Palynology of a lower Wenlock (Silurian) shelf-basin transect, Wales and the Welsh Borderland

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I dedicate this thesis to my wife Sue, whom I love dearly and who has been a constant source of encouragement in the mammoth mental and physical task that constitutes a PhD.

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ABSTRACT

Well-exposed lower Wenlock sections and borehole sequences, representing various facies along a shelf-basin transect in Wales and the Welsh Borderland, have been sampled for palynomorphs. Primary attention is paid to the type area in Shropshire, including stratotypes of both lower and upper boundaries of the Sheinwoodian Stage, with sampling as close as 10cm through the boundary horizons. The study has been extended into other sequences on the shelf, to nearshore facies in the Bristol area and to basinal sections in North Wales.

Total organic residues were recovered using quantitative processing techniques and absolute palynomorph abundances were determined. Both transmitted light and scanning electron microscopes were used to work on strew-mounted residues allowing detailed morphological study of the palynomorphs. Techniques were developed for allowing remounting of gold coated SEM cover slips, for transmitted light study, and for permanent records.

Taxonomic focus is on the acritarchs and the chitinozoans; forty-one acritarch genera and one hundred and seven species and eleven chitinozoan genera and twenty-eight species are systematically described. Ten acritarch species, one chitinozoan genus and three chitinozoan species are new. One genus and species of trilete spore is also systematically described. In addition scolecodonts, graptolite fragments, melanosclerites, chitinous hydroids and amorphous kerogen were recovered and their distribution noted.

The exceptionally well-preserved assemblages recovered from the deeper water shelf sections (including the Eastnor Park and Lower Hill Farm boreholes and Whitwell Coppice section) contain 80-2000 acritarchs/g, and 10-60 chitinozoans/g, while the species diversity index (Fisher et al. 1943) for these sections varies between 0.35 and 30.2. The nearshore/shallow water sections (including Tortworth and Dolyhir) yield a well preserved palynomorph assemblage of low abundance (0.024 to 1.14 palynomorphs/g) and low species diversity (0.35 to 3.8). The poorly preserved assemblages of the basin (including the Pistyll Quarry section and the Llanrwst and Conway composite sections) contain 0 to 4.6 palynomorphs/g and species diversity varies between 0 and 4.8. Palynomorph absolute abundances and species

diversity are compared and contrasted, both are considerably higher in the inner shelf and shelf sections than in the nearshore/shallow water and outer shelf and basinal sections.

Distribution of the organic residues through the different sections is illustrated and discussed and the acritarchs and chitinozoans are used for biostratigraphical refinement. Taxa ranges and relative frequencies are illustrated by computer drafted figures for each section; graphical techniques are also used for correlation purposes as are summary logs of range data.

In addition to vertical palynomorph distributional patterns through a studied section, palynomorph assemblage distributional patterns are also discussed and illustrated by graphical representations for the different palaeoenvironments represented by the shelf-basin transect. It is noted that the chitinozoans generally prefer deeper water; on the outer shelf the genera Ancyrochitina Eisenack 1955a and Cingulochitina Paris 1981 and in the basin the genera Sphaerochitina Eisenack 1955a and Conochitina Eisenack 1931 are dominant. With the acritarchs thin-walled leiospheres and short-spined Michrystridium Deflandre 1937 emend. Staplin 1961 appear to have a preference for nearshore/shallow water environments. The acritarchs are most abundant and diverse on the shelf with the acanthomorphs being the dominant group. Basinal sections are dominated by small thick-walled leiospheres and relatively abundant short-spined fat-bodied Veryhachium Deunff ex Downie 1959. Marine and inshore indices adapted from Richardson & Rasul (1990) are also used to highlight assemblage contrasts over the shelf and basin.

From the biostratigraphical results a new biozonational scheme for the early Wenlock is proposed, based on the recorded stratigraphical ranges of diagnostic taxa. Three existing acritarch biozones (the Deunffia brevispinosa, Deunffia furcata and Eisenackidium wenlockensis biozones) have their boundaries changed on new stratigraphical range information and one new zone, the Helosphaeridium malvernensis Biozone is proposed. Two new chitinozoan biozones, the Calpichitina (Densichitina) densa and Cingulochitina cingulata biozones are also proposed. The palynomorph biozones are related to the established graptolite biozones (see Bassett et al. 1975) in the Whitwell Coppice section and the Lower Hill Farm borehole in the Wenlock type area.

The thermal maturity of the different sections is calculated by the use of the Acritarch Alteration Index (AAI) of Legall et al. 1981, which is a method of calibrating palaeotemperatures. For consistency in results only the acritarch genus Leiosphaeridia Eisenack 1958 emend Downie & Sarjeant 1963 was used. For the shelf sections the AAI is low and varies between 2 and 4 (indicating palaeotemperatures of 60-70°C), in contrast the thermal maturity of the basinal sections is much higher, with an AAI of 5 showing palaeotemperatures in the range 90-460°C and probably towards the higher end of that range.

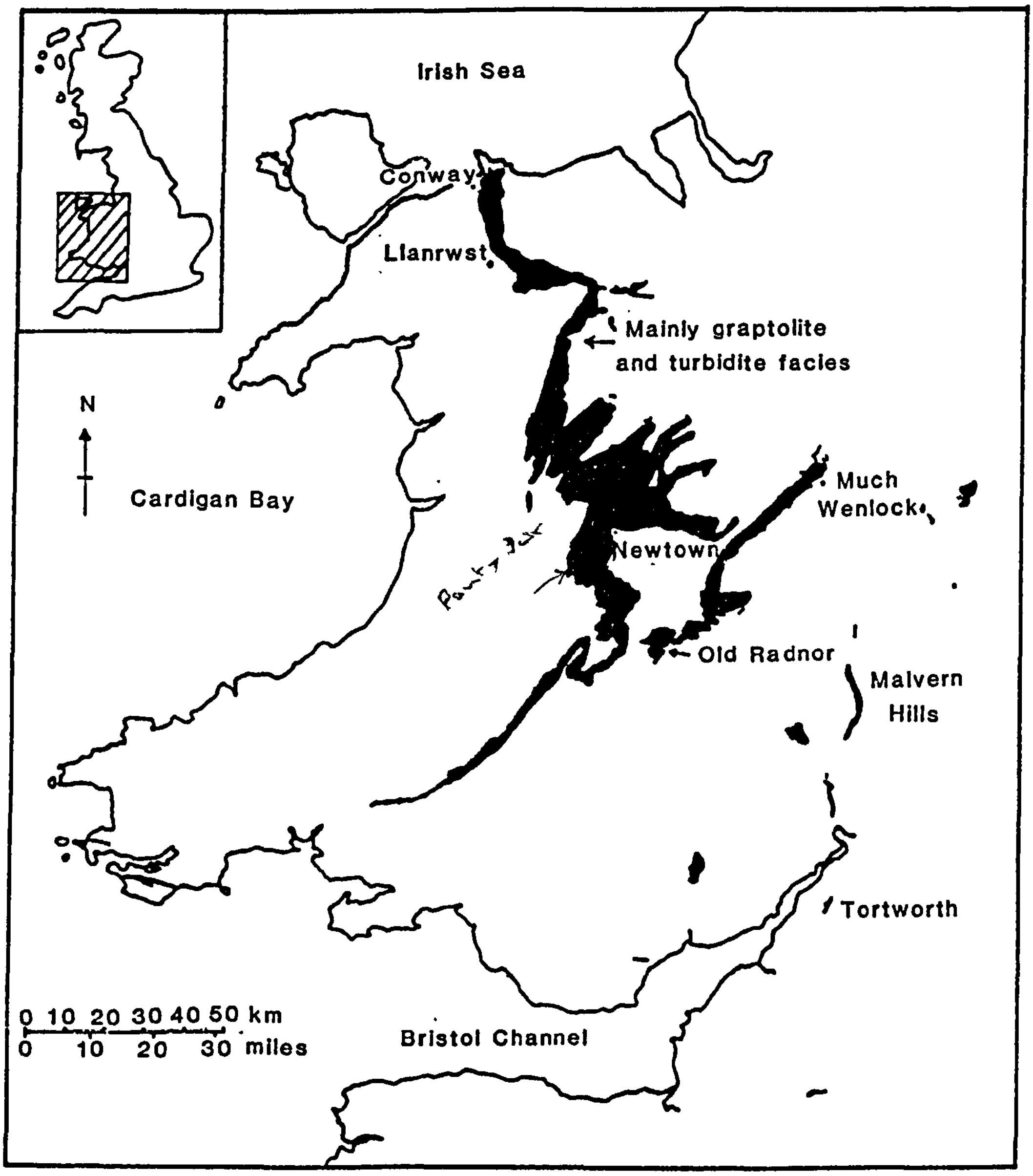


Fig. 1. Outcrop and location map of the Wenlock rocks of Wales and the Welsh Borderland (shown in black) (after Bassett 1974).

CHAPTER 1

'Even God cannot change the past' Aristotle.

1.1. Introduction

Venlock was a term first introduced by Murchison (1833, 1834, 1835) for sediments in Shropshire between the top of his Caradoc Sandstone (i.e. the top of the present Llandovery Series) and the Ludlow rocks. It was later in 1839 (p. 409) that he grouped the Venlock rocks as a formation. Lapworth in 1880 (p. 48) used the term Salopian for strata of Venlock and lower Ludlow age; numerous authors have since used the name Salopian, especially for rocks in graptolitic facies. Jones (in Evans & Stubblefield 1929, p.89) suggested that if Salopian was to be retained, it should consist of the whole of the Venlock and Ludlow; in recent literature the term Salopian has become obsolete.

Rocks of Venlock age outcrop in a broad band from North Wales (Gwynedd) through central Wales (Powys), into south west Wales (Dyfed). They also outcrop in their type area along Venlock Edge (Shropshire) and in the south west continuation of that outcrop in the Old Radnor area (Powys). There are also a number of inliers in the central and southern Welsh Borderlands and South Wales in which Venlock rocks outcrop, these include the Malvern Hills and the Tortworth Inlier (Fig.1).

For more than one hundred years correlation in the Welsh Borderland and Wales was based principally on lithostratigraphy. The inadequacies of biostratigraphical correlation between the shelly shelf of the Venlock type area and the graptolitic sequence led Cocks et al. (1971, p. 104) to conclude that the time was not yet ripe for the formal erection of stages within the Venlock Series. At that time, three informal divisions of lower, middle and upper Venlock were used, the middle Venlock incorporating the graptolite biozones of Cyrtograptus rigidus and C. linnarssoni (Cocks et al. 1971, fig. 2).

In 1971 the stratigraphy committee of the Geological Society established a Venlock working group, to determine the feasibility of setting up Venlock stages. The recommendations of the working group, which were accepted by the stratigraphy committee, were published by Basset et al.

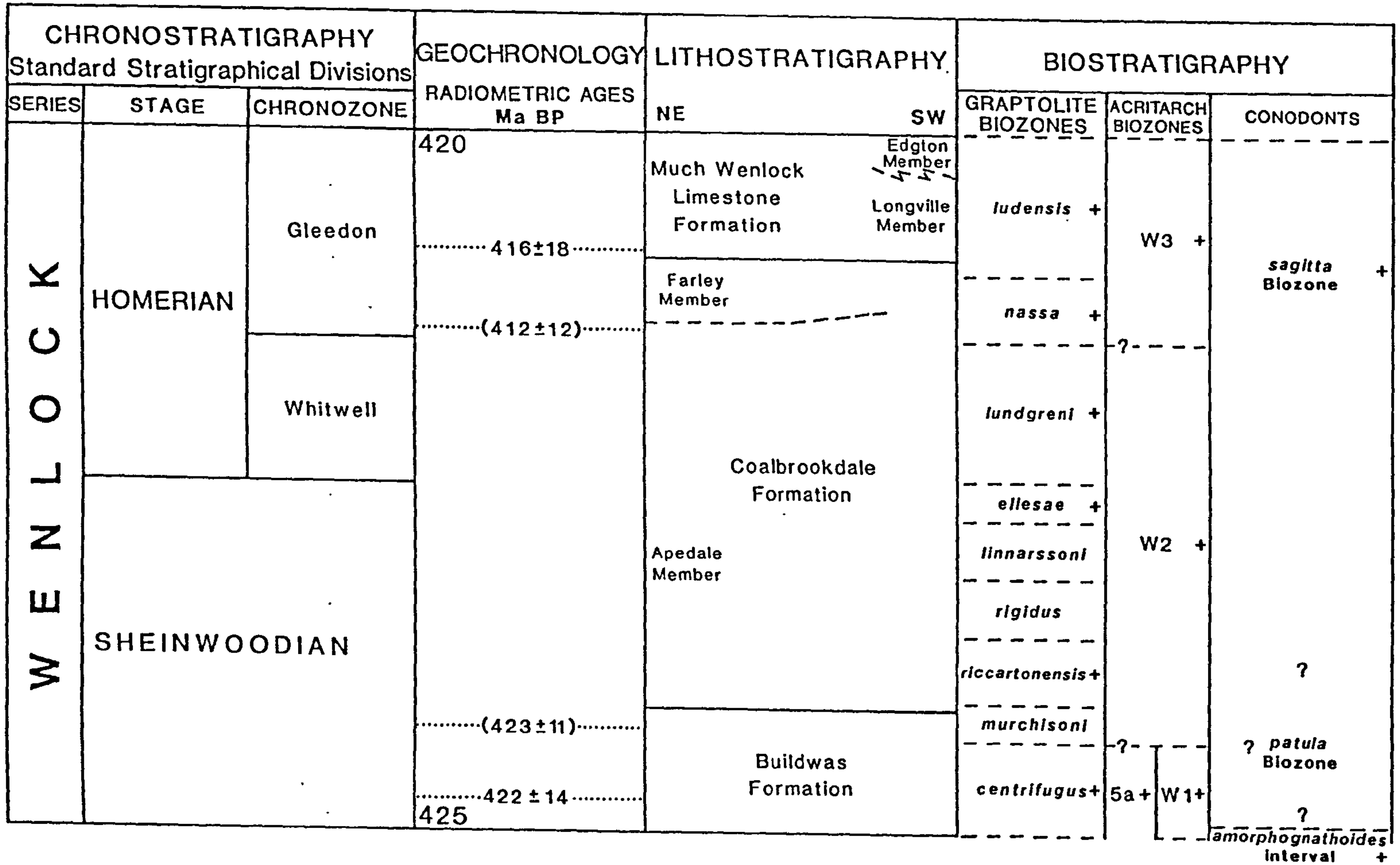


Fig. 2. Summary of stratigraphical classification in the Wenlock Series based on the type area, with data for biostratigraphical correlation and geochronological calibration; graptolite biozones marked with a cross are those whose presence is definitely established in the type area on the basis of the appropiate zonal taxa. Radiometric ages shown in brackets have analytical errors considered to be outside an acceptable range (after Bassett 1989).

(1975). The working group established a chrono-, litho- and biostratigraphy in order that the type area could be considered as an international stratotype (Fig. 2). The whole area was geologically remapped and to complement surface sections, a borehole was sunk through much of the sequence at Lower Hill Farm (SO 5817 9788).

The biostratigraphical study of the working group in the Venlock type area was largely based on the graptolites which 'in contrary to previous belief' (Bassett et al. 1975, p. 6) were found to be common enough to establish an almost complete graptolite sequence from the upper Llandovery crenulata Biozone to the late Venlock ludensis Biozone. Other macrofossils were also considered; in particular brachiopods (Bassett et al. 1975, p.8). The working group proposed a subdivision of the Venlock Series into the Sheinwoodian and Homerian stages with the upper Homerian Stage divided into lower Whitwell and upper Gleedon chronozones.

Complementary work in the Venlock type area on the palynomorphs has been undertaken by Downie (1959, 1960, 1963), Hill (1974a, 1974b), Dorning (1981a, 1981b, 1981c), Swire (1990) and Dorning & Hill (1991 'in press'). Mabillard (1981) and Mabillard & Aldridge (1982, 1985) looked at microfossil distribution (acritarchs, chitinozoans, conodonts, foraminifera and ostracodes) at the designated standard section for the base of the Venlock Series (and the Sheinwoodian Stage) at Hughley Brook, near Leasows Farm, in an attempt to establish a detailed microfossil biostratigraphy. Mabillard (1981) and Mabillard & Aldridge (1983) also looked at a number of other sections recognising the Llandovery/ Venlock boundary as accurately as possible elsewhere in the Venlock type area and in other parts of the Welsh Borderland and Wales.

This thesis presents the results of a project undertaken to supplement the macrofossil data provided by the Venlock working group (Basset et al. 1975) and the microfossil data of Mabillard (1981).

The aims of the project are:

1. To establish a detailed palynomorph biostratigraphy and to look at assemblage variations in the standard section for the base of the Homerian Stage and its (lower) Whitwell Chronozone at Whitwell Coppice.

Chronostratigraphy Standard Stratigraphical Division			Wenlock Edge	Tortworth	Malvern Hills	Central Eastern Wales	Dolyhir	North Wales
WENLOCK	Homerian	Whitwell	Coalbrookdale Formation 199m	Brinkmarsh Formation 244m	Coalbrookdale Formation 180–270m	Penstrowed Grits Formation	Shales and siltstones 90m? faulted contact	Lower Nantglyn Flags Group 325–625m
	Sheinwoodian						Dolyhir Limestone 24–60m	Denbigh Grits Group 1100m
			Buildwas Formation 40m	Pycnactis Band	Woolhope Limestone 15–60m	Nant-ysgollon Shales 40m	faulted contact Precambrian	

Fig. 3. Correlation of the studied sections. (after Bassett 1974)

2. To establish a detailed palynomorph biostratigraphy and to look at assemblage variations for the Sheinwoodian and early Homerian (Whitwell) of the British Geological Survey's (BGS) Lower Hill Farm borehole.

3. To record biostratigraphies and palynomorph assemblage variations in other sections, including a borehole of similar age (the BGS Eastnor Park borehole), from other parts of Wales and the Welsh Borderlands.

4. To look at overall palynomorph assemblage variations for the studied early Wenlock, nearshore to offshore, palaeoenvironmental transect.

5. To investigate differences in thermal maturation (Acritarch Alteration Index AAI) of the palynomorph assemblages from the studied sections.

In addition to the Whitwell Coppice section and Lower Hill Farm borehole, studied sections include two composite sections from North Wales (the Llanrwst and Conway sections) and one from Central Wales (the Pistyll Quarry section), a section from Dolyhir near Old Radnor, a British Geological Survey borehole cored at Eastnor Park in the Malvern Hills, and a section from the Tortworth area of Gloucestershire (Figs. 1,3).

1.2. Facies development and depositional environments in the early Wenlock of Wales and the Welsh Borderlands

Easterly and southerly transgression of the Llandovery sea from Central Wales across the Welsh Borderland (Ziegler *et al*. 1968; Bridges 1975) established the geographical setting within which Wenlock rocks were deposited. Ziegler (1970) synthesized the evolution of the Lower Palaeozoic geosyncline during Silurian times and updated the palaeogeographical maps of Wills (1951).

By the late upper Llandovery the north-west margin of the Midland block, which formed the eastern and southern shoreline of the shelf sea, passed close to the northern coast of the present Bristol Channel in a south-west to north-east direction through the English Midlands (Ziegler 1970, fig. 5). For the early Wenlock (Fig. 4) the shoreline was subsequently modified, running through Dyfed south of Milford Haven and north of Freshwater East and Freshwater West, where the lowest Wenlock is missing,

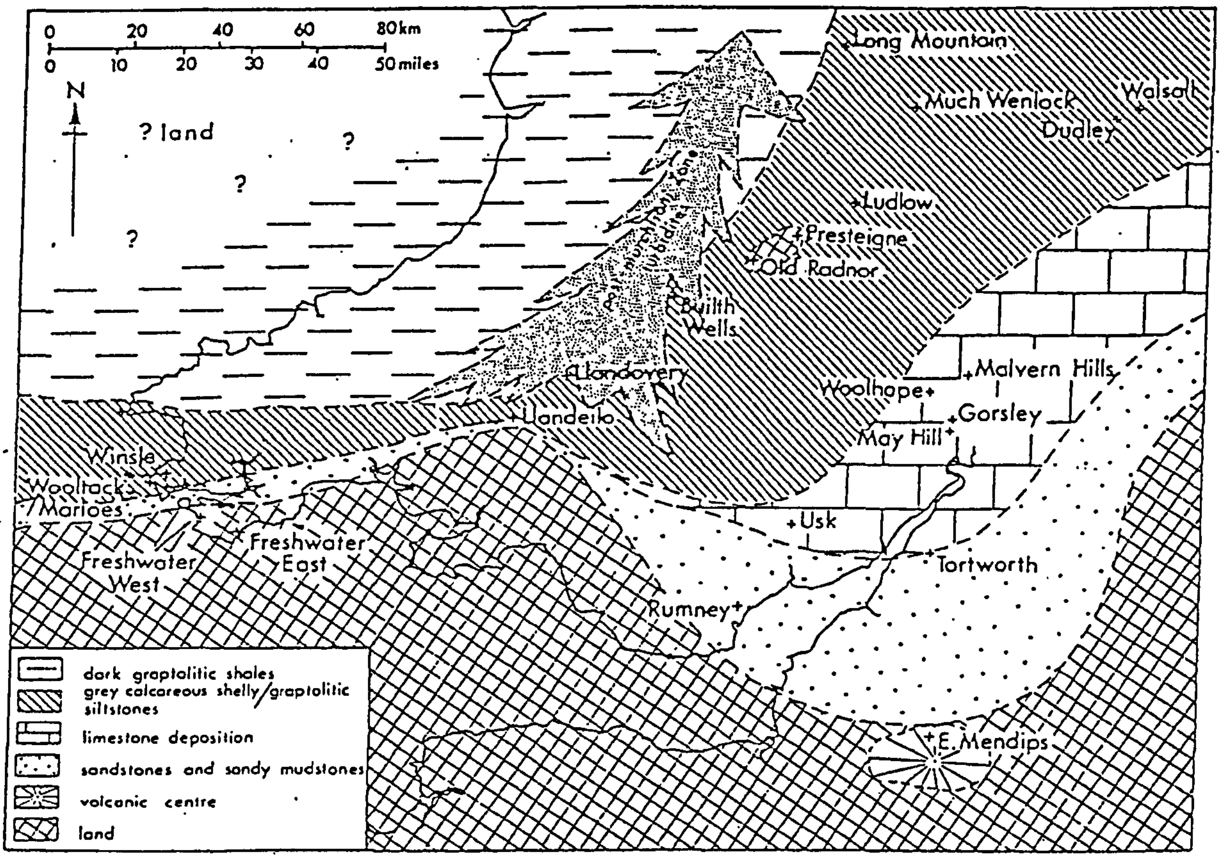


Fig. 4. Generalized reconstruction of early Wenlock palaeogeography and patterns of sedimentation in the Welsh Borderland and South Wales.

(after Bassett 1974)

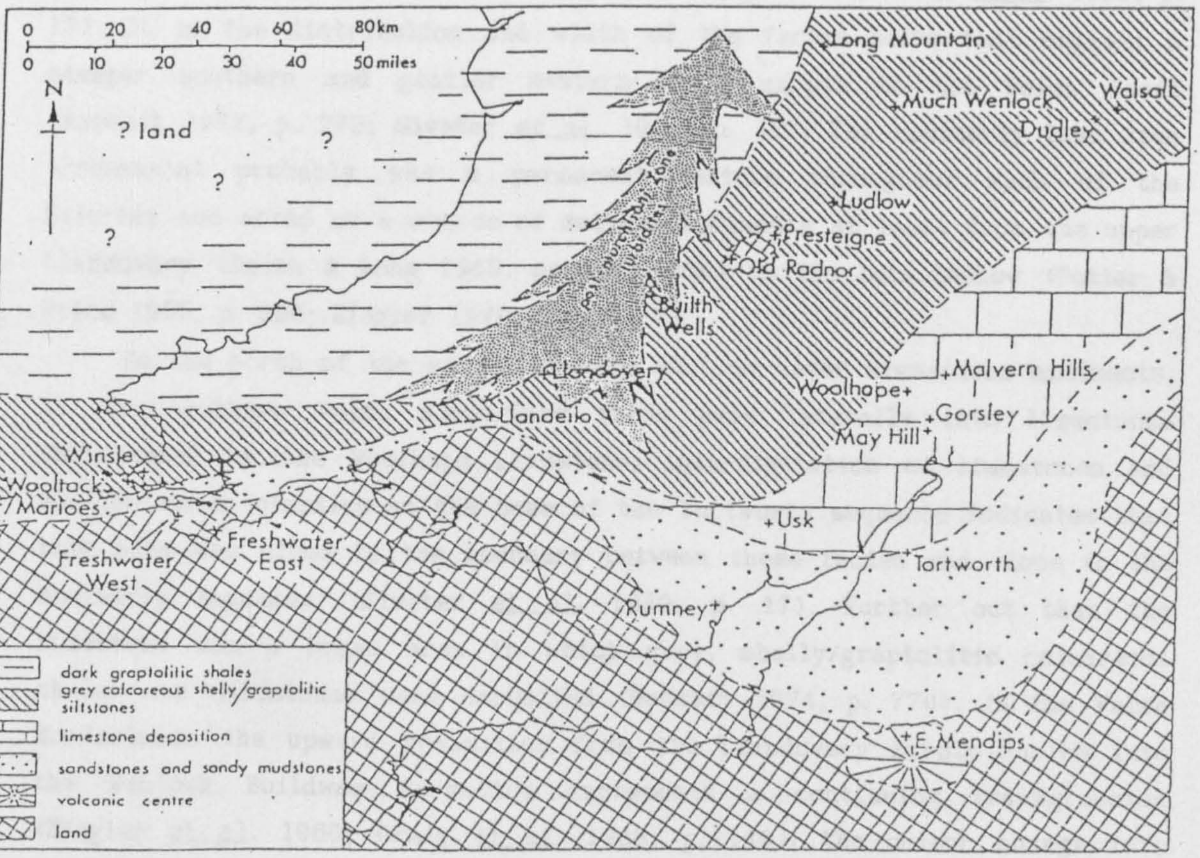


Fig. 4. Generalized reconstruction of early Wenlock palaeogeography and patterns of sedimentation in the Welsh Borderland and South Wales.

(after Bassett 1974)

and in a broad projection towards Llandeilo; here shallow-water facies indicate the proximity of land (Bassett 1974, p. 770; Siveter et al. 1989, p. 17). It is the distribution and width of the facies belts that suggest a steeper southern and gentler eastern shelf margin to the Welsh Basin (Bassett 1974, p. 772; Siveter et al. 1989, p. 17). The southerly land area (Pretannia) probably was a permanent feature throughout much of the Silurian and acted as a source of deltaic sediments at least from the upper Llandovery (Smith & Long 1969, pp. 243, 250) to the late Ludlow (Potter & Price 1965, p. 396; Ziegler 1970, figs. 4-7).

To the north of the shoreline were shallow-water arenaceous sediments; in the southern Welsh Borderland these pass laterally into limestones represented by the Woolhope Limestone; interdigitation of limestones and shallow water clastics at the base of the Tortworth sequence indicates that this area was close to the boundary between these facies and close to the southerly landmass (Siveter et al. 1989, p. 17). Further out than the limestone was a broad area in which grey, shelly/graptolitic calcareous shales and siltstones were deposited (Bassett 1974, p. 770). In the Welsh Borderlands the upward transition from the Llandovery Purple Shales into the Wenlock Buildwas Formation represents a continuing transgression (Ziegler et al. 1968; Greig et al. 1968, p. 148); the colour change into grey-green beds, represents lower water energy, a reduction in the supply of terrigenous sand and silt and a corresponding increase in deposition of carbonate mud (Bassett 1989, p. 72). This offshore shift is seen as only minor. Lack of terrigenous sediment meant that the Buildwas carbonates could concentrate enough to form nodular limestone bands, these are characteristic of the lower and upper parts of the succession (Bassett 1989, p. 72).

The common presence of shell debris and of rippled horizons suggests continued influence of currents on the Buildwas sediments and probably a proximity to storm wave base (Bassett 1989, p. 72). The Buildwas faunas are recorded as containing essentially the same ecological indicators as those of the Purple Shales (Bassett et al. 1975, p. 8) and are dominated by Dicoelosia assemblages typical of Boucot's (1975) Benthic Assemblages 4-5 on the relatively deep part of the outer platform (see also Hurst 1975b; Hurst et al. 1978; Calef & Hancock 1974). Most taxa are naturally small, especially the brachiopods (Bassett 1989, p. 72). Boucot (1975, p. 51) emphasised the fact that shells in low energy offshore environments are generally smaller than those of inshore communities. Whittard (1928, p. 752; 1952, p. 168) had earlier suggested that these small shells are parts of stunted assemblages.

The Apedale Member indicates a continuing transgression to even lower energy conditions into early-mid Sheinwoodian and Homerian times. The sediment is muddy, uniform and mostly structureless (Bassett et al. 1975, p. 4). The presence of only few benthic faunas including rare, thin-shelled brachiopods and mud dwelling trilobites and the dominance of graptolites and nautiloids suggests an outermost platform setting (Benthic Assemblage 6 of Boucot 1975) for the Apedale biotas (Bassett 1989, p. 72). Transgressive deepening was maintained through this interval and the shoreline retreated even farther to the east and south-east across central England (Bassett 1974, p. 772). Although limestones are not represented westwards beyond Llandeilo (Bassett 1974, p. 772), a narrow grey calcareous shelly/graptolitic siltstone facies (the middle Coralliferous Group) can be followed across western Dyfed (south-west Wales); this is consistent with the closer spacing of the fossil communities from upper Llandovery times onwards (Ziegler 1970, figs. 4-7) and a steeper palaeoslope. In the same facies belt, (see Fig. 4) but further offshore at Old Radnor in Powys (central eastern Wales), the shallow-water Dolyhir and Nash Scar algal limestones developed on top of a fault-bounded Precambrian topographic high along the Church Stretton Lineament (Siveter et al. 1989, p. 18; Bassett 1974 p. 772; Woodcock 1988).

In the Welsh basin turbidity currents flowed north-eastwards along the axis to deposit greywackes and grits from riccartonensis Biozone times onwards (Cummins 1957). All of the basinal sediments, including those in Powys (central-eastern Wales) and particularly those in Gwynedd (north-west Wales) suffered submarine sliding and slumping (Jones 1937, 1939). After a brief period in which mainly fine-grained sediments were laid down, slumping again took place and on an increasingly extensive scale, culminating in the wholly disturbed middle Wenlock deposits seen in Gwynedd (Llanddoget Formation), which are believed to have slumped towards the north-north-east (Jones 1937). They are seen extensively in North Wales and thin markedly eastwards (Warren et al. 1984, fig. 5). In the middle to early upper Wenlock in Gwynedd quiescent conditions prevailed in which fartravelled turbidity currents, deposited calcareous siltstones, silty mudstones and laminated (graptolite) muddy siltstones in a poorly-oxygenated environment (the Lower Nantglyn Flags Group) (Cummins 1957). The source of all the turbiditic sediments may have been a submarine rise (George 1963, p. 18) or an Irish Sea landmass to the west or south-west of Wales (Jones 1938, p. lxxxvii; George 1963, pp. 14-18; Ziegler 1970, p. 456; Siveter et al. 1989, fig. 8). It has been proposed that the sediment that now constitutes the Denbigh Grits and Lower Nantglyn groups may have been channeled west to east along a trough (Cummins 1957; Siveter et al. 1989).

1.3. Geochronology

Chronometric results based on fission-track dating of zircons obtained from bentonites at four levels in the Wenlock Series of the Wenlock type area have been published by Ross et al. (1978, 1982) (Fig. 2). There has since been criticism on the methodology and statistical accuracy of these determinations in relation to their validity in accurately defining in absolute terms the time scale (e.g., McKerrow et al. 1980; Gale et al. 1980; Gale & Beckinsale 1983; McKerrow et al. 1985); Green (1985) though has defended at least some of the criticism.

Two subsequently recalculated dates from the Wenlock give an age of 422±14 Ma for the basal Buildwas Formation (centrifugus Biozone), and 416±18 Ma for the lower Much Wenlock Limestone Formation (ludensis Biozone; see McKerrow et al. 1985, p. 76; Gale et al. 1980, p. 13). From these various dates and from consistent figures derived from Llandovery and Ludlow rocks, it appears that the length of the Wenlock Period was only some 5 million years, the base being close to 425 Ma Bp and the top at about 420 Ma Bp (see Snelling 1985 for summary). The (minimum of) nine graptolite biozones recognised through the Wenlock therefore give a potential resolution of correlation of almost 0.5 million years each (Bassett 1989, p.73).

CHAPTER 2

TECHNIQUES

2.1. Extraction methods

2.1.a. The standard technique

Acritarchs and chitinozoans were extracted using techniques similar to those described by Neves & Dale (1963 pp. 775-776); Sarjeant (1974 pp. 129-133) and Phipps & Playford (1984, pp. 1-23). A summary of the process used is as follows:

a) Clean the rock sample by scrubbing with disinfectant or if necessary etch in hydrochloric acid (HCl) or nitric acid (HNO_3). Place cleaned rock sample into a thick polythene bag, and break into 'pea' size chunks by striking the sample with a geological hammer on an anvil, care being taken not to split the bag. If the sample is not indurated then a pestle and mortar can be used to break down the sample. Thoroughly clean all work areas and equipment after the 'breakdown' of each sample to avoid contamination.

b) Weigh out 100g of the 'chunks' of mudstone or calcareous siltstone or alternatively 1kg of limestone and then place the sediment into labelled 500ml or 1 litre, hydrofluoric acid (HF) resistant, polypropylene containers.

c) Treat each sample first with warm 40 to 50% HCl (approximately 300-400ml) to remove the carbonate, leave the sample in the acid until it stops effervescing (this is normally for 12 hours but it can be longer if the sample is a limestone or carbonate rich sediment) then pour the HCl away. Add 40% HF (approximately 250ml) and stir daily with a polypropylene rod until all the rock is disaggregated.

d) After disaggregation decant samples a number of times with warm water until all the HF is removed and neutrality is attained (this can be tested with the use of universal indicator paper).

e) If disaggregation is not complete, a number of other oxidants can be used to achieve total breakdown; these include 40% nitric acid (HNO_3), Schulze's Solution (saturated potassium chlorate ($KClO_3$) and concentrated nitric acid (HNO_3)), boiling hydrochloric acid (HCl) and fuming nitric acid (HNO_3). Differing quantities can be used for different amounts of time to achieve the required results, although in the present study these oxidants were only occasionally used.

f) Samples are then sieved; set up a sieve tower with a top mesh of 200µ (to remove any remaining insoluble residue), a middle sieve of 53µ (the chitinozoan fraction) and a base sieve of 10µ (the acritarch fraction). Wash residues thouroughly through each stage of the tower to ensure separation of the fractions. Dry any insoluble residues in an oven and keep a record of their weights.

g) Using a clean glass pipette, place each fraction (the acritarch and chitinozoan) into a 50ml centrifuge tube in which a few drops of 10% HCl have previously been placed; fill the tubes with zinc bromide solution (specific gravity 2.0 or more).

h) Centrifuge the two fractions from each sample in centrifuge tubes at 2500 r.p.m. for 15 minutes, this ensures separation of any remaining mineral residue from the organic fraction. Remove the supernatent (organic residue) using a clean glass pipette and wash each fraction thoroughly in a glass sinter funnel (pore size 2) to remove all traces of the zinc bromide. Recover organic residues with a clean pipette and place each fraction in a separate small labelled glass vial.

i) Examine organic residues under a light microscope and if necessary treat with 10% nitric acid (HNO_3) for ten minutes to remove pyrite. Any obscuring organic film can be dispersed with the use of 2% potassium hydroxide solution (KOH).

j) Mount half of the residues for each sample if palynomorph abundance is high and all of the residue if palynomorph abundance is low, onto 22 x 22mm coverslips and set in glue (Petropoxy 154). Depending on the amount of organic residue recovered, two slides of the fine fraction (mainly acritarchs) and two of the coarse (mainly chitinozoans) should be produced for each sample. Retain any remaining organic residue for reappraisal or SEM work.

2.1.b. Quantitative palynomorph preparation

2.1.b.1. For the shelf sections of the Lower Hill Farm and Eastnor Park boreholes and Whitwell Coppice (after Downie 1958, p. 332)

In these sections where palynomorph abundance is relatively high, the above procedure was followed (a to j), except that only 0.5g of a rock sample was processed; chemical breakdown was total leaving, if possible, no mineral residue. All the organic fraction was mounted onto slides and a total count was maintained. The final counts were multiplied by two to give numbers per gram of palynomorphs.

2.1.b.2. For the basinal sections of Pistyll Quarry, Llanwrst and Conway and the shelf sections of Tortworth and Dolyhir

In these sections where palynomorph abundance is relatively low, the total organic residue from the breakdown of 100gm samples was mounted. A figure for absolute abundance was achieved by maintaining a total palynomorph count for these samples and then dividing by 100 to give numbers per gram (if there was some insoluble residue for a sample then the weight was taken into account with the calculation).

2.2. Preparation techniques for the scanning electron microscope (SEM)

Follow the above procedures (a to i) then strew mount organic residues onto coverslips and attach to small Cambridge stubs with high vacuum wax. Apply conducting paint to improve electrical contact between the coverslips and the stubs and then gold coat. Prepared cover slips are logged by systematically traversing from top right to bottom left. Permanent records are maintained by mounting the gold coated cover slips onto slides with glue (Petropoxy 154), the high vacuum wax is removed with chloroform.

2.3. Rock sample documentation

The British Geological Survey samples are registered in the series MPA 26084-26045 for the Lower Hill Farm borehole, and MPA 28416-28410 and MPA 28484-28474 for the Eastnor Park borehole.

Collected sections each had their own unique code (for instance WC for Whitwell Coppice); with each sample being initialled (PS) and possessing its own number (1-?). The repository for these these samples is the Department of Geology, Leicester University. A field notebook was kept for reference purposes. Rock sample documentation used for each section is noted in the individual lithological descriptions for the sections collected (CHAPTER 3).

2.4. Specimen location

Individual specimens on strew mounted microslides, and on the remounted SEM slides are located with 4 digit England finder references. Mainly because of their small size, it was not always possible to relocate acritarch specimens on the remounted SEM slides.

2.5. Photography

Optical microscope black and white photographs were taken on a Zeiss photomicroscope using Kodak Pan X film. SEM photographs were taken on a ISI-SX-30 using Ilford FP4 film. Negatives were developed using Pattison Acutol, and printing was achieved with the use of Kodak D163 print developer, and Kodak fixer. Colour photographs were taken on a Leitz Labrolux microscope using an Olympus OM10 camera and Kodak film, negative developer, print developer and fixer.

2.6. Palynomorph abundance and species diversity

For all the studied sections abundances are referred to in two ways. Absolute abundances of palynomorphs are expressed as numbers per gram of rock processed. Relative abundances in each sample (for an individual taxon or palynomorph group) are represented as a proportion (%) of the total recovered palynomorph assemblage from that interval.

The species diversity for each section is calculated using an index formulated by Fisher et al. (1943), which takes account of the relationship between the total number of individuals and the total number of species in a sample. The index is:-

$$S = a \log_e \left(1+\frac{N}{a}\right)$$

where S is the number of species, N the number of individuals and a the index of diversity. The number of individuals within each species is not taken into account, but the index enables some prediction of the number of species that would be expected in a collection of any given number of individuals.

2.7. Biostratigraphy

Biostratigraphical results of all of the studied sections are represented by computer drafted normalized palynological frequency diagrams; these show relative abundances of recovered palynomorph species for each studied sample (refer to Fig. 9). The second line to the right of the shaded area is the relative abundance of a taxon multiplied by twenty-five times, the line highlights the occurrence of taxa with low relative abundances which otherwise might not be readily observed on the charts. The diagrams range each species by highest occurrence, and illustrate the ranges against a representative lithological log with sample depths, sampling horizons and biostratigraphical details, including palynofloral zones also displayed.

The other plot used for each section is the summary log (see appendix 2), where for correlation purposes species highest occurrences (↰), species first occurrences (↲), the acme of species (•) and species presence (+) (when a possibly stratigraphically useful species occurs in only a single sample) are illustrated.

For the two borehole sections (the Lower Hill Farm borehole and Eastnor Park borehole) the depths in metres have been obtained from the appropiate logs. For the rest of the sections (Tortworth, Whitwell Coppice, Dolyhir, Pistyll Quarry, the Llanrwst section and the Conway section), sampling horizons related to the representative lithological sections are illustrated. Depths for these sections have been estimated; they have been calculated from details recorded in the field about sample spacing and from relevant publications which detail overall sedimentary thicknesses in particular regions.

CHAPTER 3

STRATIGRAPHY AND PALYNOMORPH BIOSTRATIGRAPHY

3.1. The Type Wenlock Area, Wenlock Edge, Shropshire

Wenlock Edge is a 25 km long escarpment that extends from just north of the River Severn south-westwards via Benthall Edge and past the town of Much Wenlock to the River Onny, north of Craven Arms. The escarpment is of Much Wenlock Limestone, while the lower ground of Ape Dale and Coalbrookdale, below the escarpments, is occupied by softer rocks of the uppermost Llandovery and lower to middle Wenlock Series. (the Purple Shales, Buildwas Formation and Coalbrookdale Formation). The Purple Shales and Buildwas Formation are exposed in stream sections in the north-east of the area, although in the south-west they are hidden by a blanket of superficial deposits (Greig *et al*. 1968, p. 151). The middle part of the Wenlock (Coalbrookdale Formation) is in low lying agricultural land, although exposures in streams, old trackways, and modern road cuttings together give a composite stratigraphical succession; some idea of this overlapping coverage is given by fig. 8 of Bassett *et al*. (1975). An important source of information in support of the surface exposures is the core from the Lower Hill Farm borehole (Bassett *et al*. 1975, p. 4; [D.E. White 1974, p. 4]).

3.1.a. Lithostratigraphy and historical review

The Wenlock sequence of Wenlock Edge was first divided by Murchison (1833, p. 475) into an uppermost Wenlock Limestone division and an underlying 'Lower Ludlow Rock or Die Earth'; later in 1834 (p.14) he referred the latter unit to the Wenlock Shale and this terminology was used in subsequent accounts (1835, 1839, 1854-1872). Salter & Aveline (1854, pp. 63,71) separated the Wenlock Shale from what remained of Murchison's 'Caradoc Sandstone' and the shale was restricted to the unit that overlies the Purple Shales. The Wenlock Shale was then subdivided further by Davidson & Maw (1881, pp. 102-104; in Davidson 1882, pp. 67-70) into the 'Basement Beds', 'Buildwas Beds', 'Coalbrookdale Beds', and 'Tickwood Beds', the subdivision also included shales from above the Wenlock Limestone that were included within the Wenlock; Lapworth & Watts (1894, p. 325) followed this classification fully, Watts (1925, p. 346) partly followed it. Whittard (1928, p. 752) suggested subsequently that the 'Basement Beds' infact belong to the Llandovery Purple Shales; most authors have also followed Murchison's original definition (1839) including shales above the Wenlock Limestone within the Ludlow.

Whittard (1952, p. 169) suggested that graptolites recorded by earlier authors, notably Whittard (1928, 1932), Das Gupta (1932), and Pocock et al. (1938), from the 'Buildwas Beds' belong either to the rigidus or linnarssoni Biozone, implying that the centrifugus, murchisoni, riccartonensis, and rigidus biozones are absent, and he went on to suggest that there is a considerable stratigraphical break below the 'Buildwas Beds'. Cocks & Rickards (1969, pp. 224-227) looking at all previous records of graptolites from the uppermost Llandovery and lowest Wenlock of Shropshire suggested (pp. 228-229) that there is no large sedimentary break in the type area at the 'Purple Shales/Buildwas Beds' junction which 'approximately coincides with...the base of the centrifugus Biozone'. Aldridge (1972) and Mabillard & Aldridge (1985) recorded an amorphognathoides Zone conodont fauna from the Buildwas Formation of the type area; correlatives of this zone elsewhere are known to span the Llandovery/Wenlock boundary, lending support to a centrifugus Biozone age for at least part of the formation. Graptolites recorded by Pocock et al. (1938) from the lower part of the overlying 'Coalbrookdale Beds' suggested a correlation with the linnarssoni Biozone and the higher faunas from this unit suggested the ellesae, lundgreni, and possibly part of the ludensis biozones.

Discrepancies in chrono-, litho- and biostratigraphy were 'tidied up' in a report on the type Wenlock Series (Bassett et al. 1975); stage (Sheinwoodian and Homerian) and chronozone (Whitwell and Gleedon) names were given to the early and late Wenlock with named international type sections for chronostratigraphical boundaries being described. The Buildwas, Coalbrookdale and Much Wenlock Limestone Beds of Davidson & Maw (1881, 1882) became the Buildwas, Coalbrookdale and Much Wenlock Limestone formations (Fig. 2). A graptolite fauna recovered from the British Geological Survey Lower Hill Farm borehole (Bassett et al. 1975, p.5, fig.3) established definitely for the first time the presence of the centrifugus

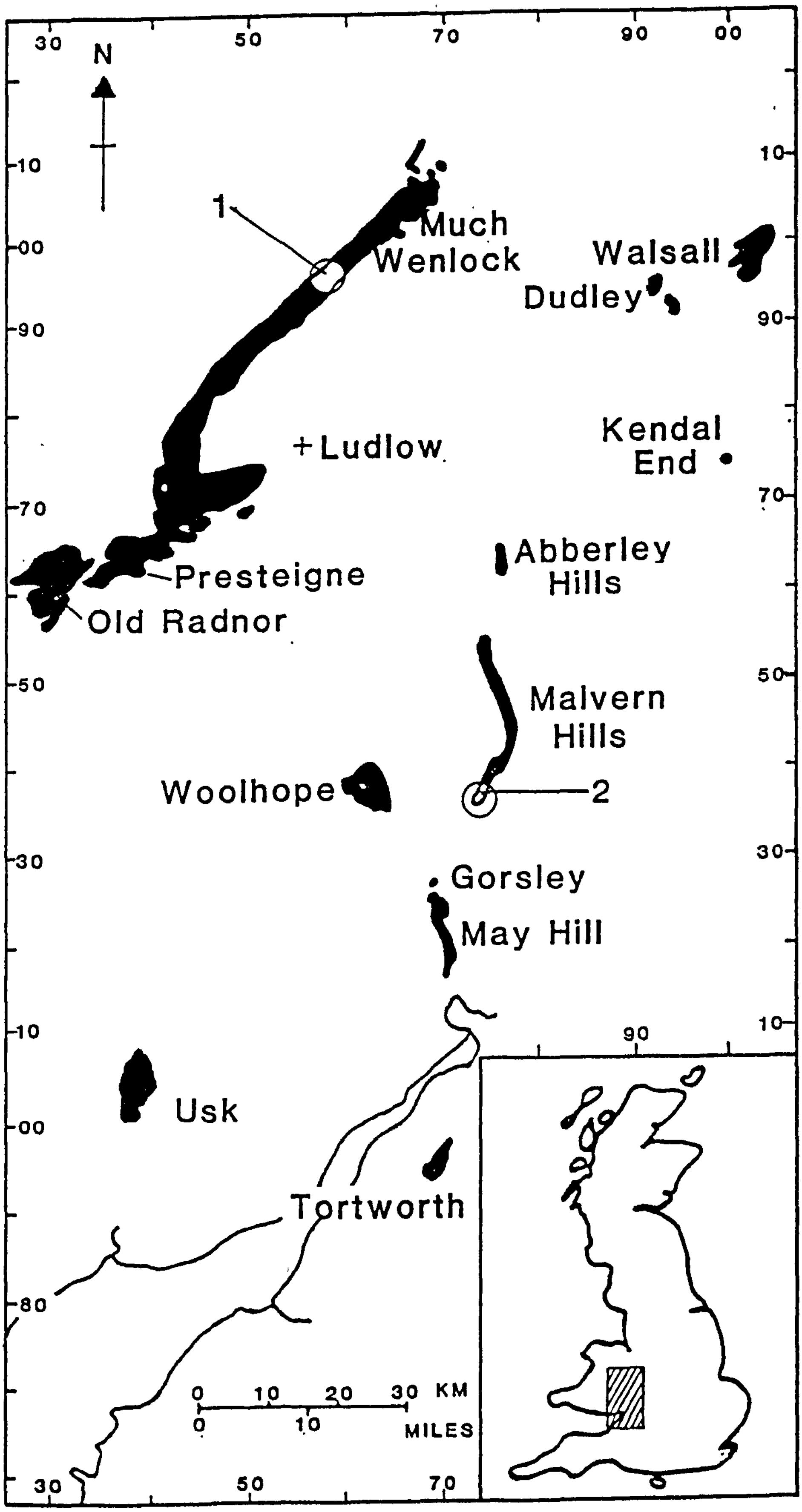


Fig. 5. Locality map for the two borehole sections, 1. B.G.S. Lower Hill Farm Borehole (SO 5817 9788), Shropshire and 2. B.G.S. Eastnor Park Borehole (SO 7437 3809), Hereford and Worcester; outcrop of Wenlock strata is shown in black.

and *riccartonensis* graptolite biozones, although graptolites defining the *murchisoni*, *rigidus*, and *linnarssoni* biozones were 'lacking or doubtful'. The revised chronostratigraphy, with the Venlock Series divided into Sheinwoodian and Homerian Stages, was subsequently accepted by the Subcommision on Silurian Stratigraphy of the IUGS and the area is now ratified as the international type for the series (Martinsson *et al*. 1981; see also Holland 1980a,b, 1982, 1984, 1985; Bassett 1979a, 1985, p.89).

The Coalbrookdale Formation has recently been split formally into two members; the lower Apedale Member overlain by the Farley Member (Bassett 1989, p. 56-57), the latter being synonymous with the Tickwood Beds of Davidson & Maw (1881) which are recognised in the restricted sense of Pocock and others (1938, p. 112) as 24 to 27m of beds below the Much Venlock Limestone Formation.

3.1.b. A review of Venlock palynological research

The first detailed palynological study of material from the type Venlock was undertaken by Downie (1959, 1960, 1963) who described hystrichospheres (i.e. acritarchs) from the 'Wenlock Shale' (the Buildwas and Coalbrookdale formations). Most of the subsequent publications have also concentrated on the acritarchs (Lister 1970; Lister & Downie 1974). Hill (1974b) and Hill & Dorning (1984) published acritarch biostratigraphies for the Llandovery rocks of the Llandovery type area and for the lower most Venlock of some sections from the Venlock type area. Dorning (1981a, 1981b, 1981c, 1987), Dorning & Bell (1987) and Dorning & Hill (1991 'in press') published the results of an extensive study of acritarch biostratigraphy and palaeoenvironmental distribution in the Llandovery, Venlock and Ludlow of the English Midlands, Welsh Borderlands and Wales. Ranges of the more stratigraphically useful Silurian microfossil taxa, including acritarchs and chitinozoans, were recorded by Aldridge *et al*. 1980 and the distribution of these taxa across the Venlock shelf was discussed by Aldridge *et al*. 1981. Mabillard (1981) and Mabillard & Aldridge (1985) in a study of microfossil distribution across the Llandovery / Venlock boundary recorded the occurrences of acritarch and chitinozoan taxa in lower Venlock strata from the Venlock type area.

Chitinozoans from the Venlock of Wales and the Welsh Borderlands were first described by Eisenack (1977, 1978), who illustrated forms from the

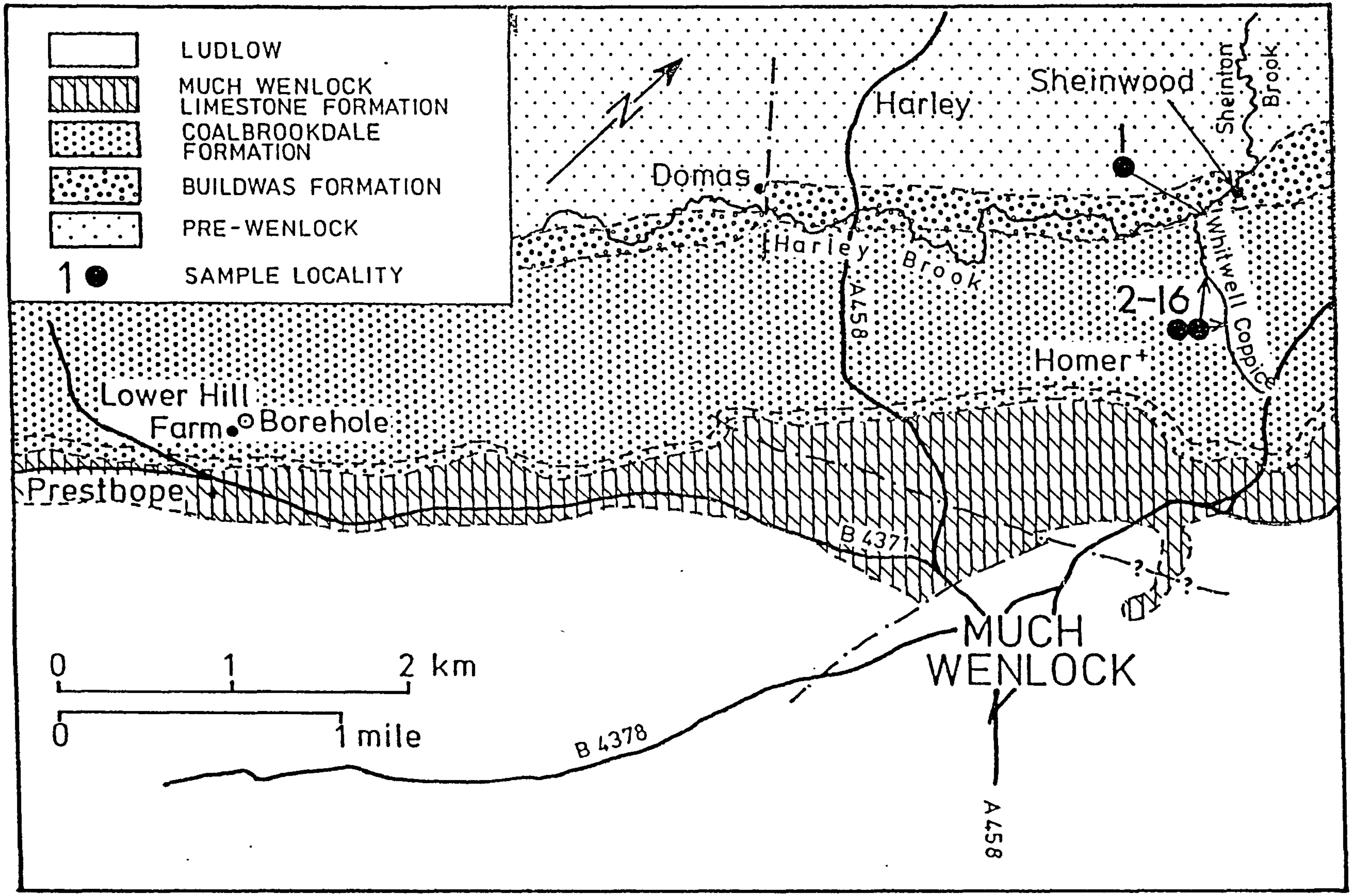


Fig. 6. Outcrop in the Wenlock type area (after Bassett et al. 1975).

Much Wenlock Limestone Formation at Dudley in the West Midlands. Dorning (1981b) recorded the ranges of 35 chitinozoan taxa of stratigraphic value from the Wenlock and Ludlow type areas. Swire (1990) described some new chitinozoan taxa from the lower Wenlock of the type area and from the Malvern Hills.

3.2. The Lower Hill Farm borehole

In 1973, the British Geological Survey drilled the Lower Hill Farm Borehole at (SO 5817 9788), 1690m at 092° from Hughley church near Wenlock Edge, Shropshire (Figs. 5,6). This locality is on the outcrop of the upper part of the Coalbrookdale Formation, at 485ft OD and about 1.3km east south-east of the standard section for the base of the Wenlock Series in Hughley Brook. The borehole was cored to 247.50m in a sequence comprising part of the Coalbrookdale Formation, the Buildwas Formation, and part of the Purple Shales (Fig.7). Detailed lithological and biostratigraphical data from this borehole have been used to complement the generally poor surface exposures in the area, which include the international stratotype for the Wenlock Series (Bassett et al. 1975). In the only published micropalaeontological study to mention the borehole, Mabillard & Aldridge (1985, p.95) recorded the amorphognathoides conodont Biozone of Walliser (1964) in the Purple Shales and the lower Buildwas Formation; the top of the zone was recognised at a depth of 239.14m and the base at 242.21m.

3.2.a. Collected lithologies and lithological details

Forty samples were studied from the Lower Hill Farm borehole, twenty-seven from the Coalbrookdale Formation (Apedale Member) and thirteen from the Buildwas Formation; the average sample interval is five metres. The top sample (MPA 26045) is at a depth of 63.51-64.69m and is from the upper Coalbrookdale Formation. The deepest sample (MPA 26084) is at a depth of 239.1-239.66m and is from the base of the Buildwas Formation (239.69m as noted by Bassett et al. 1975, p.5-6). The base of the Whitwell Chronozone and therefore of the Homerian Stage on graptolite evidence is at a depth of approximately 75m (Bassett et al. 1975).

The lower Coalbrookdale Formation (Apedale Member) consists of a grey-green silty, slightly calcareous mudstone, which varies from being massive to rather shaly; ill-defined, grey-brown, argillaceous limestone nodules are

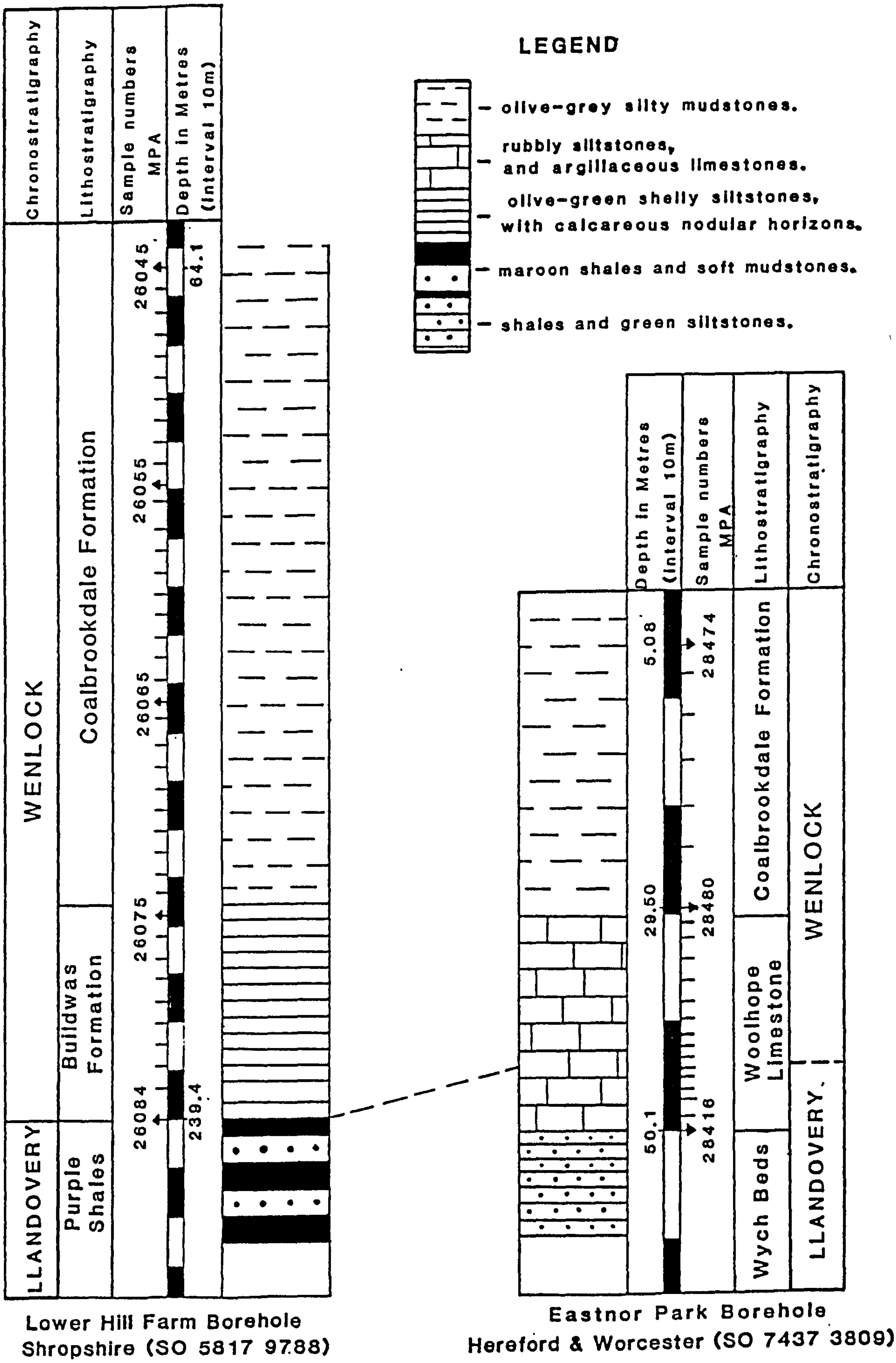


Fig. 7. Lithological sections.

sporadically developed. Shale bands (probably bentonitic) usually less than 4cm thick, are present, mainly below 45.00m (Bassett et al. 1975, p. 4). The beds lack the comminuted shells and friable/rubbly weathering of the underlying beds of the Buildwas Formation. In the Lower Hill Farm borehole the basal datum for the Apedale Member of the Coalbrookdale Formation and top of the Buildwas Formation is at 199.14m (Bassett et al. 1975, fig.3). The total recorded thickness of the Apedale Member in the Wenlock type area varies between 192m and 265m.

The Buildwas Formation consists of grey, silty, slightly calcareous mudstone, which is mainly hard and massive with a 'rubbly fracture'. Limestone bands and/or nodules are often present and shale bands which are probably bentonitic, pale grey to greenish grey, usually less than 4cm thick, occur throughout. In the Lower Hill Farm borehole the Buildwas Formation is 40m thick, although in outcrop a maximum of only some 27m can be examined (for a detailed lithological description of the Buildwas Formation refer to Bassett 1989, p.56).

3.2.b. Material

Preservation of the recovered palynomorphs is excellent and both absolute abundance (range 450-2464 palynomorphs/g; average 963 palynomorphs/g) and species diversity (range 7.7-30.2; average 18.5) is moderate to high. Thermal maturation of the palynomorphs is low, with the body colour of the acritarchs a pale lemon yellow.

3.2.c. Palynomorph distribution

Fig. 8 illustrates palynomorph absolute abundances (these samples were processed using the quantitative technique described on page 9), species diversity and the relative abundances of the different palynomorph groups, for all forty samples through the borehole section. Both species diversity and absolute abundance are highest in the Buildwas Formation and lowest in the lower Coalbrookdale Formation. The acritarchs consistently account for between 90 and 97% of the recovered palynomorphs with scolecodonts and chitinozoans accounting for between 1 and 10% and trilete spores between 0 and 5%.

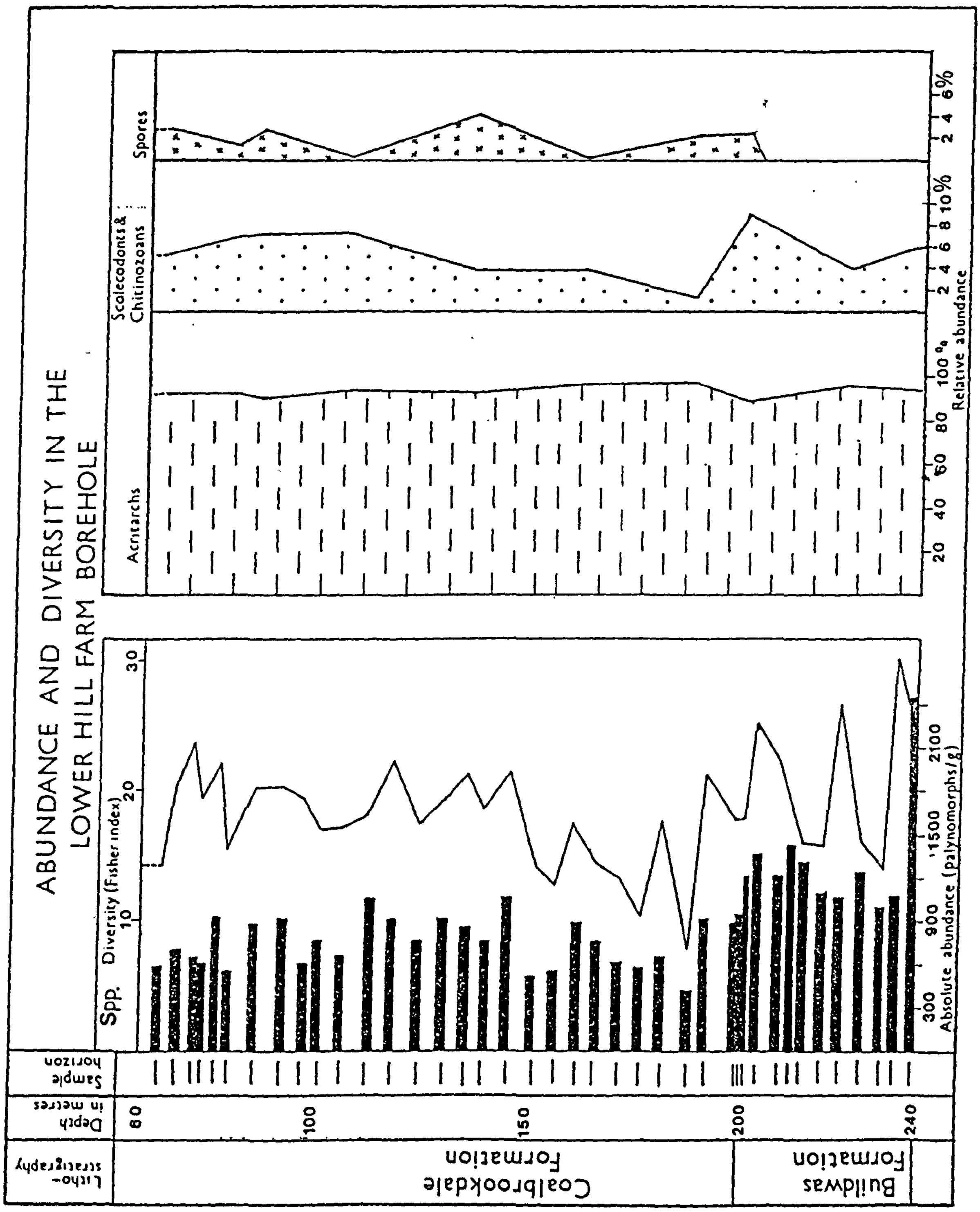


Fig. 8. Palynomorph absolute abundance and species diversity in the Lower Hill Farm Borehole.

3.2.d. Acritarchs

In comparison with other studied sections absolute abundance is high and varies between 444-2328 acritarchs/g (average 912 acritarchs/g); abundance is highest in the Buildwas Formation (range 864-2328 acritarchs/g; average 1132 acritarchs/g) and lowest in the Coalbrookdale Formation (range 498-848 acritarchs/g; average 653 acritarchs/g). Acritarchs on average account for 93% of a palynomorph assemblage. The dominant acritarch group represented are the acanthomorphs accounting for on average 53% of the acritarchs.

3.2.e. Chitinozoans and scolecodonts

Absolute abundance is low to high and varies between 6-136 chitinozoans/g (average 48 chitinozoans/g) for the section; there appears to be some link between chitinozoan and acritarch absolute abundances, with chitinozoan abundance being highest in the Buildwas Formation (range 40-136 chitinozoans/g; average 76 chitinozoans/g) and lowest in the Coalbrookdale Formation (range 6-64 chitinozoans/g; average 32 chitinozoans/g). Chitinozoans account for on average 5.5% of the palynomorph assemblage recovered.

A notable peak in both chitinozoan and acritarch absolute abundances and species diversity is observed at the base of the Buildwas Formation; this increase has been previously noted by Mabillard & Aldridge 1985 (p.93) in the Wenlock type area where a 'significant increase in abundance and diversity' was noted in the uppermost Purple Shales and in those beds which are 'transitional to those of the overlying Buildwas Formation'.

Scolecodonts are present throughout the section but are never very numerous, their absolute abundance varies between 0 and 16 scolecodonts/g (average 2.9 scolecodonts/g). The scolecodonts account for on average only 0.3% of recovered palynomorphs. There is possibly a relation between numbers of scolecodonts and conochitinid chitinozoans (the link is less tenuous in other sections); certainly both reach peaks in abundance in the same sample (MPA 26079), although the proof of a positive relationship is hampered in this section by the 'background noise' of a rich and diverse palynomorph assemblage.

3.2.f. Trilete spores and organic debris

Trilete spores are consistantly present through the section and relative to spores recovered from other sections are of low to moderate abundance (between 0-36 spores/g; average 10.4 spores/g); they account for on average 0.48% of the palynomorph assemblage. Plant cuticle, Melanosclerites spp., annular tubing, chitinous hydroids, and graptolite fragments (including prosiculae) are also present throughout the section accounting for on average 0.32% of the assemblage.

3.2.g. Biostratigraphy of the Lower Hill Farm Borehole

Lithological details, stratigraphical ranges, relative abundances of palynomorph species and the emended palynofloral biozones of Dorning 1981a, Dorning & Bell 1987 and Dorning & Hill ('1991' in press) are illustrated on a palynological frequency diagram Fig.9. The graptolite biozones (see Fig. 2) and ranges of selected taxa are illustrated on the summary log (see appendix 2).

The core samples from the Lower Hill Farm borehole have ranged depths (see appendix 1). For the sake of both the frequency diagram (Fig. 9) and the summary log (see appendix 2) each sample has just the lowest depth plotted.

The sample at the base of the Buildwas Formation (MPA 26084) at a depth of 239.14-239.66m contains a number of acritarch species, that have their highest occurrences in this sample; including the zonal species Deunffia brevispinosa Downie 1960 (see Dorning & Bell 1987 and p.60); there are also Deunffia ramusculosa Downie 1960, Domasia bispinosa Downie 1960 and Gracilisphaeridium encantador (Cramer 1970) Eisenack et al. 1973.

The interval above this to a depth of 199.14-200.05m (MPA 26074), which has been taken as the top of the Buildwas Formation (see Bassett et al. 1975, fig.3), is characterised by the stratigraphical range of the zonal acritarch Deunffia furcata Downie 1960 (see p.61) which is from 234.57-236.07m to 203.12-204.65m (MPA 26083 to MPA 26076). In this interval also are the first occurrences of the acritarchs Fractoricoronula checkleyensis (Dorning 1981a) emend. at 234.57-236.07m (MPA 26083), Alveosphaera ? deflandrei (Stockmans & Willière 1963) Priewalder 1987 at 234.57-236.07m (MPA 26083) and Ammonidium palmitella (Cramer & Diez 1972a) Dorning 1981a at 217.55-219.13m (MPA 26079) and also the highest occurrences of the

FIGURE NO. 9

Normalized Palynological frequency diagram for the BGS LOWER HILL FARM BOREHOLE, SHROPSHIRE

acritarch species *Estiastra barbata* Downie 1963 at 234.57-236.07m (MPA 26083) and *Deunffia monospinosa* Downie 1960 at 222.48-223.95m (MPA 26080). The complete stratigraphical range of the chitinozoan *Salopochitina bella* Swire 1990 at 234.57-236.07 to 227.10-228.68m (MPA 26083 to MPA 26081) falls within this interval; the highest occurrence of *Calpichitina (Densichitina) densa* (Eisenack 1962) is at 203.12-204.65m (MPA 26076)

The interval from 199.14-200.05m (MPA 26074) to a depth of 76.73-78.28m (MPA 26049) is characterized by a number of species highest occurrences, but there are few species first occurrences and also few palynomorphs with stratigraphical ranges restricted to this relatively broad interval. *Helosphaeridium malvernensis* Dorning 1981a has a stratigraphical range between depths 170.79-172.26m (MPA 26067) and 76.73-78.28m (MPA 26049) and is proposed as the zonal marker for the interval (see biozonation p. 61). The acritarch species *Salopidium truncatum* sp.nov. also has a restricted stratigraphical range from 198.48-199.14m (MPA 26073) to 144.98-146.45m (MPA 26062). Within this interval also are the highest occurrences of the acritarch species *Cymatiosphaera pavimenta* (Deflandre 1945) Deflandre 1954 at 165.00-166.52m (MPA 26066), *Alveosphaera ? deflandrei* (Stockmans & Willière 1963) Priewalder 1987 at 160.25-161.77m (MPA 26065), *Fractoricoronula checkleyensis* (Dorning 1981a) emend. at 144.98-146.45m (MPA 26062), *Salopidium woolhopensis* Dorning 1981a at 134.57-136.04m (MPA 26060), *Cymatiosphaera fragilis* sp. nov. at 129.95-131.45m (MPA 26059), *Ammonidium palmitella* (Cramer & Diez 1972a) Dorning 1981a at 101.04-102.57m (MPA 26054) and *Domasia trispinosa* Downie 1960 at 79.86-81.13m (MPA 26050). The first occurrence of the chitinozoan species *Cingulochitina cingulata* (Eisenack 1937) is at 198.48-199.14m (MPA 26072) and its acme in abundance is at 85.62-87.20m (MPA 26051).

The interval between 76.73-78.28m (MPA 26049) and 63.51-64.69m (MPA 26045) is characterized by the first occurrence of the zonal acritarch *Eisenackidium wenlockensis* Dorning 1981a (see p.62) at a depth of 72.21-73.71m (MPA 26047) and the highest occurrences of *Multiplicisphaeridium cladum* (Downie 1963) Eisenack 1969a at 73.71-75.16m (MPA 26048) and the chitinozoan species *Margachitina margaritana* (Eisenack 1937) at 67.54-68.97m (MPA 26046). The interval is also identifiable by the stratigraphical range of the acritarch *Dateriocradus monterossae* (Cramer 1969a) Dorning

1981a between the depths 79.86-81.13 (MPA 26050) and 72.21-73.71 (MPA 26047).

If the type section for the Sheinwoodian/Homerian Stage at Whitwell Coppice is correlated with the Lower Hill Farm borehole, the stage boundary section correlates to between a depth of 76.73-78.28m (MPA 26049), the highest occurrence of the zonal acritarch Helosphaeridium malvernensis Dorning 1981a and 72.21-73.71m (MPA 26047), the first occurrence of the zonal acritarch Eisenackidium wenlockensis Dorning 1981a; this is in agreement with the graptolite data (the ellesae-lundgreni biozonal boundary) which places the Sheinwoodian/Homerian boundary at approximately 75m in the Lower Hill Farm borehole (Bassett et al. 1975, p.14 and fig.3).

3.3. Whitwell Coppice

3.3.a. Lithologies

The Coalbrookdale Formation (Apedale Member) exposed in Whitwell Coppice comprises a monotonous sequence of compact, well bedded blocky and conchoidally fracturing olive-grey silty-mudstones which dip eastwards at 2-3°. Graptolites and orthoconic nautiloids occur throughout the section, together with rare, smooth brachiopods. Interbedded at different horizons are thin beds of bentonitic clay. Three samples were collected at various exposures along the coppice and thirteen samples were collected at the stratotype section for the base of the Homerian Stage and base of the Whitwell Chronozone in the banks of a small tributary stream (Fig. 10).

3.3.b. Collected Section

Sample 1. (WCA/PS 1). (sample locality 58 of Bassett et al. 1975: SJ 6129 0206). Silty mudstone near base of Coalbrookdale Formation (Apedale Member), collected in rill course on east bank of Sheinton Brook.

Sample 2. (WCA/PS 2). (sample locality 63 of Bassett et al. 1975: SJ 6183 0207). Sample of silty mudstone collected from exposure in side of stream running through Whitwell Coppice.

Sample 3. (WCA/PS 3). (sample locality 64 of Bassett et al. 1975: SJ 6187 0206). From Sheinwood, immediately above junction of small stream to north-east.

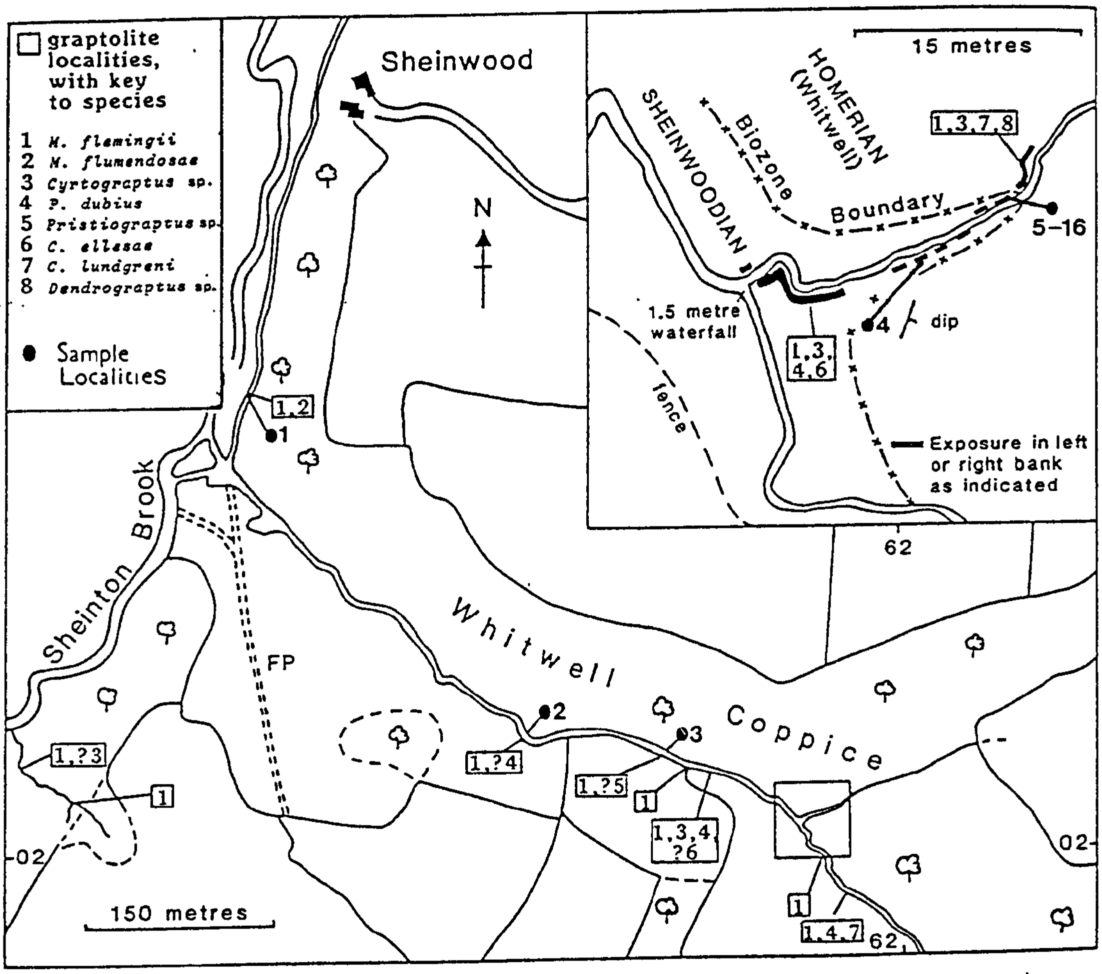


Fig. 10. Location of the stratotype base of the Homerian Stage (and Whitwell Chronozone), with data on graptolite species present immediately below and above the boundary level (after Bassett et al. 1975).

Samples 4-16. (WC/PS 1-WC/PS 13). The Sheinwoodian/Homerian Stage boundary (Fig. 11) (sample locality 66 of Bassett *et al*. 1975: SJ 6193 0204). Section in side stream to the tributary of Sheinton Brook flowing through Whitwell Coppice, 500m north of Homer.

The stage boundary is defined at the point where the *ellesae*-*lundgreni* (graptolite) biozonal boundary cuts the north bank of the stream; low down in the collected section (approximately 1m below the stage boundary) is a bentonitic clay horizon (this was used as a marker in the monotonous mudstone sequence even though this horizon was not referred to in the locality description of Bassett *et al*. 1975).

Sample WC/PS 1 is from below the marker bentonite in the right (south) bank of the stream, samples WC/PS 2-13 are at 10cm intervals through the siltstone above the bentonite. One graptolite was recovered from the section (sample WC/PS 11, 90cms above the top of the bentonite) and has been identified (Dr. D. White of the British Geological Survey) as *Barrandeograptus* aff. *carruthersi* (Lapworth). Lapworth (1876) described *Cyrtograptus carruthersi* from the Riccarton Beds (i.e. early Wenlock) of Scotland. Elles (1900) recorded (but did not figure or describe) *C. carruthersi* from the 'highest beds of the Wenlock Shale' (of the Welsh Borderland) and from Bohemia, where it is associated with *C. lundgreni*.

From the 1.5m of strata below the stage boundary Bassett *et al*. (1975, p.14) listed *Cyrtograptus ellesae*, *Monograptus flemingii* and *Pristograptus dubius*. Above the boundary, *Cyrtograptus lundgreni* occurs with *M. flemingii*, *P. dubius* and *Dendrograptus*.

3.3.c. *Material*

Preservation of the recovered palynomorphs is excellent and both absolute abundance (range 328-1904 palynomorphs/g; average 1051 palynomorphs/g) and species diversity (range 16.0-24.6; average 19.3) is moderate to high. Thermal maturation of the palynomorphs is low with the acritarchs typically possessing a lemon-yellow body colour.

3.3.d. *Acritarchs*

Absolute abundance varied between 320-1888 acritarchs/g (average 1025 acritarchs/g) for the section; abundance was lowest in sample WCA/PS 1 (sample 58 of Bassett *et al*. 1975) which is from the lower Coalbrookdale

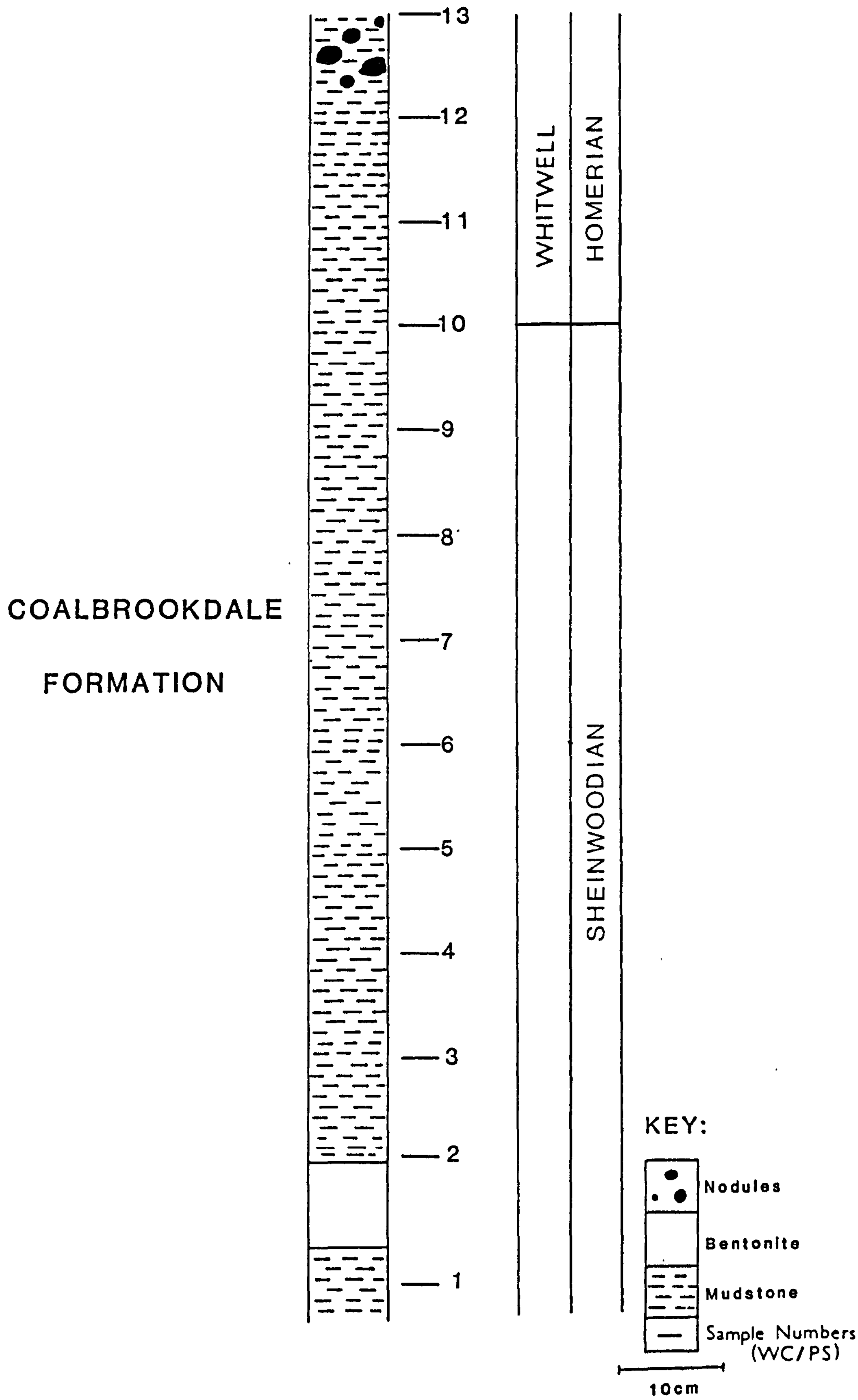


Fig. 11. Stratotype section for the base of the Homerian Stage (and Whitwell Chronozone) at Whitwell Coppice.

Formation (riccartonensis graptolite Biozone), and is highest in sample VCA/PS 2 (sample 63 of Bassett et al. 1975; linnarssoni graptolite biozone). Acritarchs are the dominant palynomorph group accounting for an average 93.5% of an assemblage. The most numerous acritarch group is the acanthomorphs which on average consitute 54% of a recovered acritarch assemblage.

3.3.e. Chitinozoans and scolecodonts

Absolute abundance for the section varied between 8-60 chitinozoans/g (average 26 chitinozoans/g); abundance is highest in the samples that cross the Sheinwoodian/Homerian stage boundary (samples VC/PS 1-13). The peak in absolute abundance (in WC/PS 13) coincides with the epibole of the chitinozoan Cingulochitina cingulata (Eisenack 1937) which in a number of samples is at least three times as numerous as the remainder of the chitinozoan assemblage. This dominance of Cingulochitina cingulata (Eisenack 1937) has previously been noted from the middle part of the Coalbrookdale Formation in the Wenlock type area (Aldridge et al. 1979, p.433; 1981, p.21).

Chitinozoans in total account for 5% of the recovered palynomorph assemblage. Scolecodonts were rare accounting for only 0.25% of recovered palynomorphs in the section.

3.3.f. Spores and Organic Debris

Trilete spores ,relative to other sections, are quite abundant accounting for on average 1.25% of the palynomorph assemblage; absolute abundances are between 4-36 spores/g and the peak abundance of the trilete spores is in sample WC/PS 3. Organic debris in the form of graptolitic fragments, plant cuticle, Melanosclerites spp. and chitinous hydroids were recovered at different horizons but are never very abundant.

3.3.g. Comparisons and contrasts in the palynomorph distributions of the the Whitwell Coppice section and the Lower Hill farm borehole

Fig. 12 illustrates palynomorph absolute abundances (these samples were processed using the quantitative technique described on page 9) and species diversity for all collected samples through the Coalbrookdale Formation at Whitwell Coppice. Absolute abundance (328 palynomorphs/g) and species diversity (12.9) is lowest in the stratigraphically lowest sample in

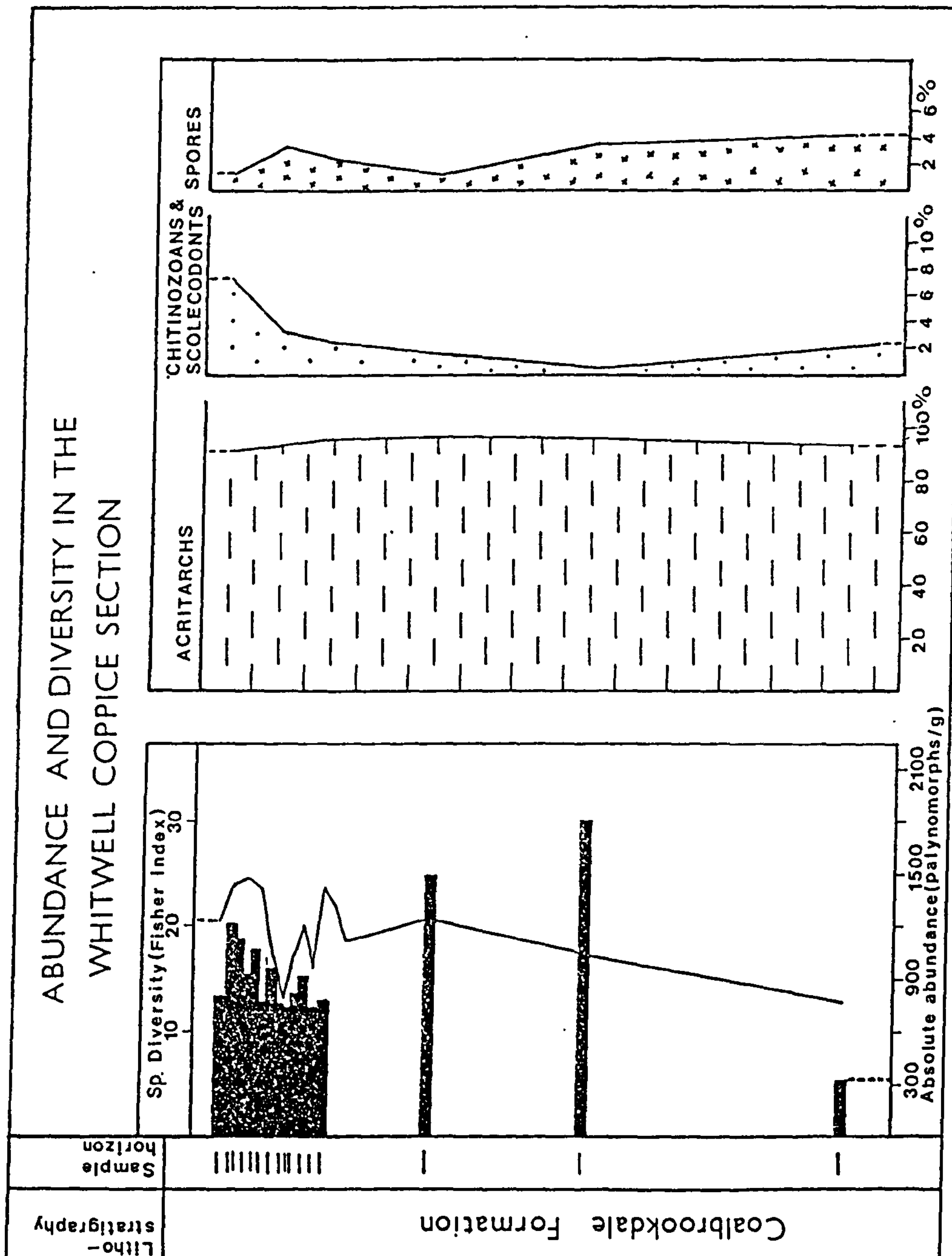


Fig. 12. Palynomorph absolute abundance and species diversity in the Whitwell Coppice section.

the Whitwell Coppice section (WCA/PS 1; sample locality 58 of Basset et al. 1975). According to Basset et al. (1975), this sample locality is at the base of the Coalbrookdale Formation just above the top of the Buildwas Formation (the Buildwas Formation is not actually exposed in Whitwell Coppice). The recovered palynological assemblage from this sample is comparable with the assemblage recovered at a similar horizon in the Lower Hill Farm borehole at a depth of 187-191m where absolute abundance (360 palynomorphs/g) and species diversity (7.7) is correspondingly very low.

Over the Sheinwoodian/Homerian boundary (samples VC/PS 1-13) in Whitwell Coppice there is an average species diversity of 19.8 and an average absolute abundance of 862 palynomorphs/g. The correlatable depth of 72-78m in the Lower Hill Farm borehole yields an average species diversity of 20.87 and an average absolute abundance of 703 palynomorphs/g. Taking quite considerable palynomorph diversity and absolute abundance fluctuations into account throughout the two sections these figures are comparable.

3.3.h. Biostratigraphy of the Whitwell Coppice Section

For the Whitwell Coppice section there are two computer drafted palynological frequency diagrams, one (Fig. 13a) for the older more widely spaced samples (WCA/PS 1-3) below the Sheinwoodian-Homerian Stage boundary and another (Fig. 13b) for the samples of the stage boundary section (WC/PS 1-13).

3.3.h.1. Biostratigraphy of the samples lower than the Sheinwoodian-Homerian stage boundary

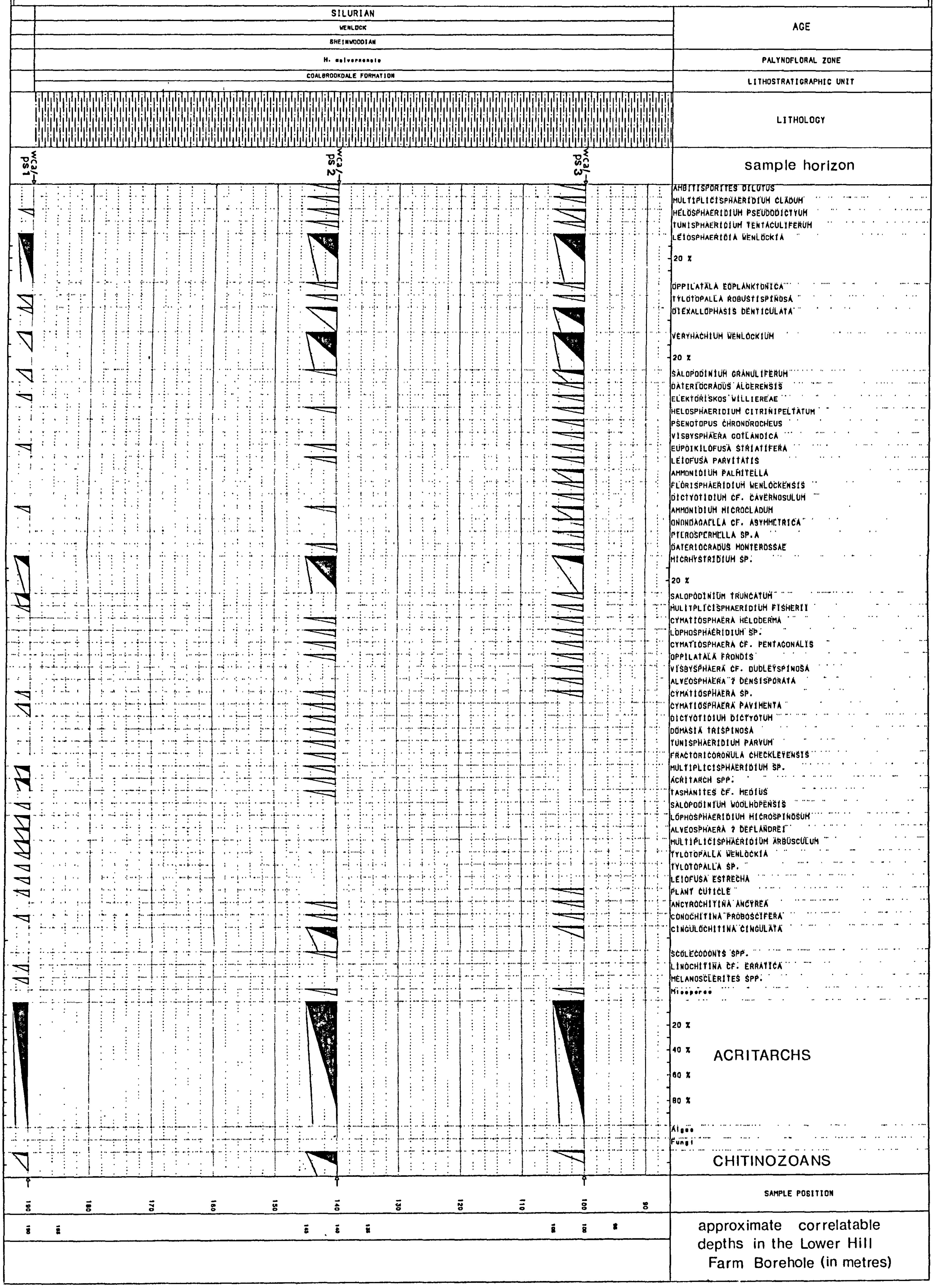
Sample WC/PS 1 (locality 58 of Bassett et al. 1975) yields a palynomorph assemblage that contains the acritarch species Alveosphaera ? deflandrei (Stockmans & Willière 1963) Priewalder 1987, Salopidium truncatum sp.nov., Salopidium woolhopensis Dorning 1981a and Cymatiosphaera pavimenta (Deflandre 1945) Deflandre 1954.

Sample WC/PS 2 (locality 63 of Bassett et al. 1975) yields a palynomorph assemblage that contains the acritarch species Fractoricoronula checkleyensis (Dorning 1981a) emend. and Cymatiosphaera pavimenta (Deflandre 1945) Deflandre 1954 and the chitinozoan species Cingulochitina cingulata (Eisenack 1937).

WHITWELL COPPICE

FIGURE NO.13a

Normalized Palynological frequency diagram for the SECTION OF WHITWELL COPPICE, SHROPSHIRE
(LOWER THAN S/H BOUNDARY)



Sample WC/PS 3 (locality 64 of Bassett *et al*. 1975) yields a palynomorph assemblage that includes the acritarch species *Alveosphaera* ? *densisporata* Priewalder 1987 and *Salopidium truncatum* sp.nov. and the chitinozoan *Cingulochitina cingulata* (Eisenack 1937).

All three samples correlate to between a depth of 170.79-172.26m (MPA 26067) and 76.73-78.28m (MPA 26049) in the Lower Hill Farm borehole, that is they correlate to the *Helosphaeridium malvernensis* Biozone (see biozonation p. 61).

3.3.j. The Sheinwoodian/Homerian boundary

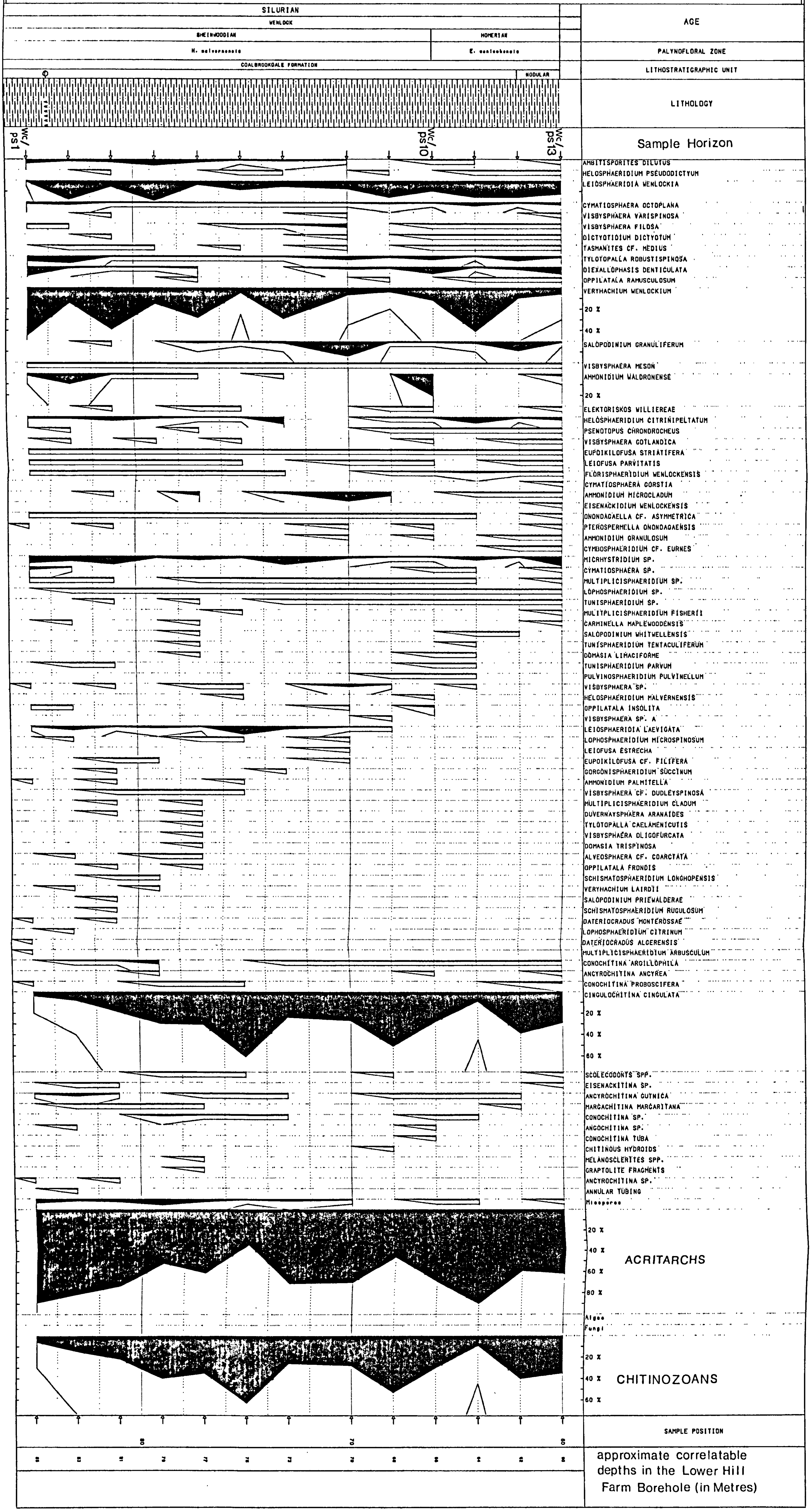
There are a number of palynomorph species in the samples that cross the Sheinwoodian/Homerian stage boundary (WC/PS 1-13) that are potentially of stratigraphical use. Worth noting are the highest occurrences of the acritarch species *Dateriocradus monterossae* (Cramer 1969a) Dorning 1981a in sample WC/PS3, *Multiplicisphaeridium cladum* (Downie 1963) Eisenack 1969a in sample WC/PS5, *Ammonidium palmitella* (Cramer & Diez 1972) Dorning 1981a in sample WC/PS6, *Helosphaeridium malvernensis* Dorning 1981a in sample WC/PS 10 (see *Helosphaeridium malvernensis* Biozone page 62) and *Domasia trispinosa* Downie 1960 in sample WC/PS11. Also worth noting are the first occurrences of the acritarchs *Leiofusa estrecha* Cramer 1964 in sample WC/PS8 and *Eisenackidium wenlockensis* Dorning 1981a in sample WC/PS13 (see *Eisenackidium wenlockensis* Biozone page 61).

The highest ocurrence of the chitinozoan species *Margachitina margaritana* (Eisenack 1937) is in sample WC/PS12 and the epibole of the dominant chitinozoan species *Cingulochitina cingulata* (Eisenack 1937) is in sample WC/PS6.

WHITWELL COPPICE

FIGURE NO.13b

Normalized Palynological frequency diagram for the SECTION OF WHITWELL COPPICE, SHROPSHIRE (Sheinwoodian/ Homerian boundary)



3.4. The Malvern Hills, Hereford & Worcester

The Malvern Hills are situated some 75 km SSE of Church Stretton and form a prominent, 12 km long, north-south chain of peaks which are dominantly formed of a Precambrian complex of igneous and metamorphic rocks. Cambrian successions in the area are well exposed, but the only Ordovician sediments are Tremadoc shales (Aldridge & Smith 1985). Thrusting affecting the Silurian of the Abberley Hills is not developed as a southerly continuation of the structural line into the Malvern Hills, therefore in the Malverns a full Wenlock succession is present along most of the outcrop (Bassett 1974, p. 760). Phipps & Reeve (1967) revised the stratigraphy and gave an outline of previous work (see Philips 1848; Groom 1910). Penn & French (1971) have also commented on the succession.

The basal lithological unit of the Wenlock with its most northerly development in the inliers of the Welsh Borderland is the Woolhope Limestone, its thickness is an average of 15-21m, although it reaches a maximum of 60m near North Malvern (Phipps & Reeve 1967, p. 343). Mainly the Woolhope Limestone consists of olive-grey, rubbly, calcareous siltstones and argillaceous limestones; these separate an upper and lower development of flaggy bedded, silty limestones (Bassett 1974; Hurst et al. 1978). The limestone contains Resserella sabrinae burringtonensis which suggests an age between the zones of C. centrifugus and M. riccartonensis (Hurst et al. 1978, p. 210); Bassett (1974) also records Costistricklandia lirata lirata and Eocoelia cf. sulcata which suggest an upper limit in the murchisoni Biozone. Phipps & Reeve (1967) refer to a terrigenous clastic member in the Woolhope Limestone and relate this to Wenlock uplift around Gorsley and in the Malverns, the clastic member in the Malverns consists of occasional silty mudstones and calcareous siltstones. The overlying Coalbrookdale Formation consists mainly of olive-grey siltstones and shales with lines of calcareous nodules (Bassett 1974, p. 760).

3.4.a. The Eastnor Park borehole

As exposure of the early Venlock succession in the Malverns is not very good, the British Geological Survey cored a borehole through the lower Coalbrookdale Formation and through all of the Woolhope Limestone into the Wych Beds (which are Llandovery in age) (Fig. 7). The borehole was cored in 1981 at a distance of 1500m north-east of Eastnor church in Eastnor Park (SO 7437 3809) (Fig. 14).

In the borehole, the lithological boundary between the Woolhope Limestone and Coalbrookdale Formation was taken by the British Geological Survey at a depth between 30.10 and 30.28m. From the sedimentary log the boundary appears purely an arbitrary one, above which the percentage of limestone decreases. The lithological boundary between the Woolhope Limestone and underlying Wych Beds at 50.10m is taken at a depth where calcareous nodular beds give way to shales and green siltstones. There are fifteen bentonite horizons at regular intervals throughout the section.

In all twenty-two samples were studied, fifteen from the Woolhope Limestone with a sampling interval of 1.5m and seven from the Coalbrookdale Formation with a sampling interval of 3m. The base of the Woolhope Limestone and the first sampling horizon is at a depth of 50.10m. Nineteen of the samples are registered in the British Geological Survey's MPA series (MPA 28410 to 28416 and 28474 to 28485); the exact depths of these are known. Three of the samples are bulk samples with ranged depths and are here documented as KD/BS 1-3 (see appendix 1).

3.4.b. Material

Preservation of the recovered palynomorphs is excellent and both absolute abundance (range 25-976 palynomorphs/g; average 306 palynomorphs/g) and species diversity (range 6-25.3; average 14.4) is moderate to high. Thermal maturation of the palynomorphs is moderate with the acritarchs typically possessing a brown body colour.

3.4.c. Acritarchs

Absolute abundance varies between 20 and 952 acritarchs/g (average 281 acritarchs/g) for the section, abundance was highest in the Woolhope Limestone and lowest over the lithological transition into the Coalbrookdale

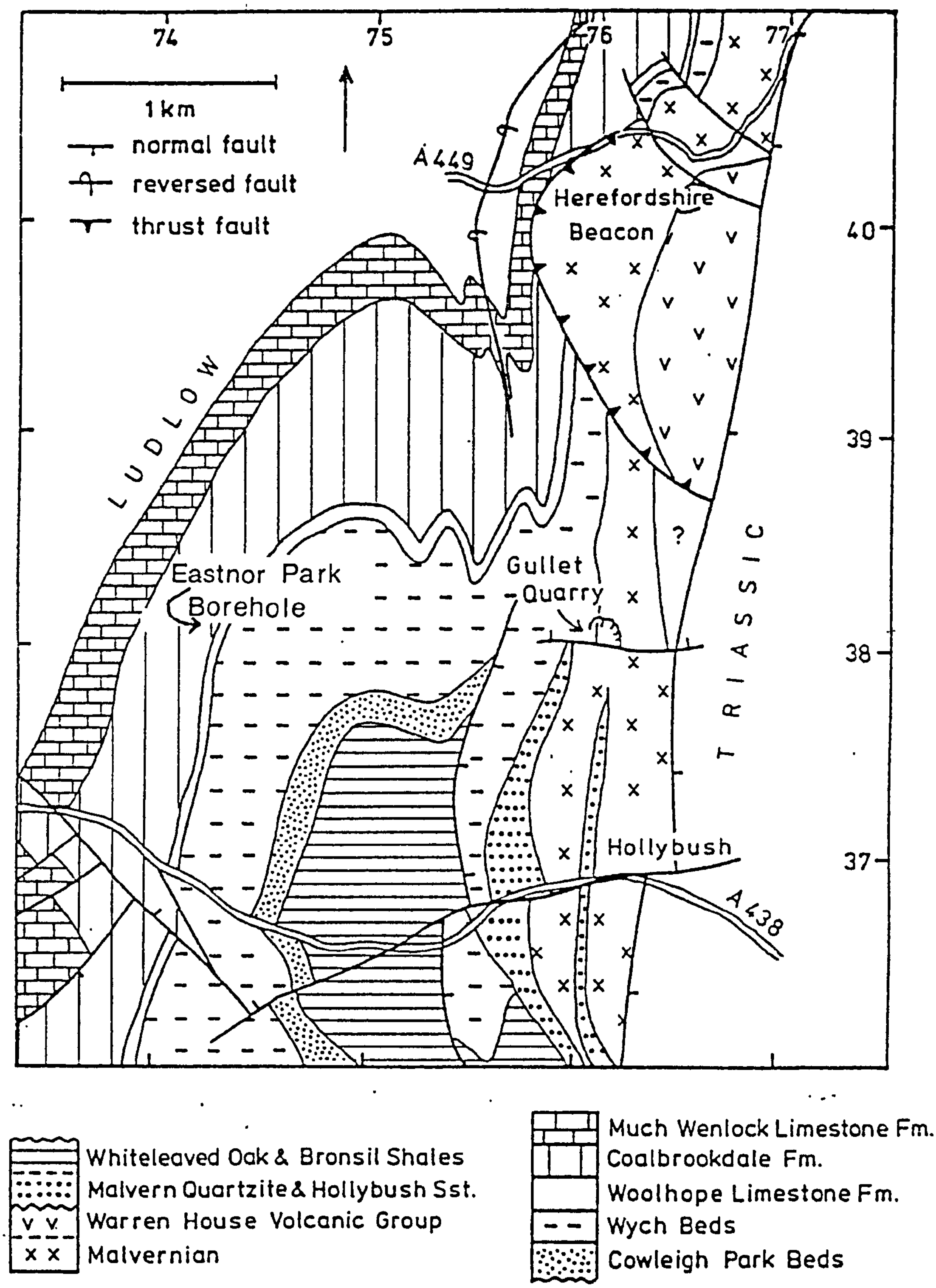


Fig. 14. Geological sketch-map of the Malvern Hills (after Aldridge & Smith 1985).

Formation. Acritarchs are the dominant palynomorph group averaging over 90% of an assemblage. The dominant acritarch group represented is the acanthomorphs accounting for on average over 60% of the acritarchs.

3.4.d. Chitinozoans and scolecodonts

Chitinozoan absolute abundance is moderate to low for the section and varies between 1 and 116 chitinozoans/g (average 20 chitinozoans/g). Abundance appears to follow no pattern; it is highest in the lower Coalbrookdale Formation and lowest in the middle Coalbrookdale Formation and the lower part of the Woolhope Limestone. There appears to be little comparison in abundance patterns between the acritarchs and chitinozoans as far as peaks are concerned although both are lowest in two samples (MPA 28478 and MPA 28481) at depths of 20.20m and 31.80m; the latter depth is from the section of the core that is transitionary from the Woolhope Limestone to the Coalbrookdale Formation. Overall, chitinozoans account for 6% of recovered palynomorphs from the section.

Scolecodonts are relatively numerous in the section (range 0-16 scolecodonts/g; average 5 scolecodonts/g) and account for 2.5% of recovered palynomorphs. They are relatively small and are thin-walled; numerical distribution appears to be associated to the distribution of conochitinid chitinozoans with matching peaks of abundance (in sample MPA 28410).

3.4.e. Spores and organic debris

Trilete spores are rare, in the whole section only 12 were observed; plant cuticle is also rare, as are Melanosclerites spp. Other organic debris in the form of graptolitic fragments, including graptolite prosiculae were recorded sporadically through the section.

3.4.f. Palynomorph distribution in the Eastnor Park borehole

Fig. 15 illustrates palynomorph absolute abundance and species diversity variations for the samples through the section; the basal fifteen samples are from the Woolhope Limestone and the top seven from the Coalbrookdale Formation. Abundance and diversity are higher in the Woolhope Limestone than the Coalbrookdale Formation, although within the Woolhope Limestone both parameters are quite variable; a reason for this is probably the lithological variability of the Woolhope Limestone in the Eastnor Park

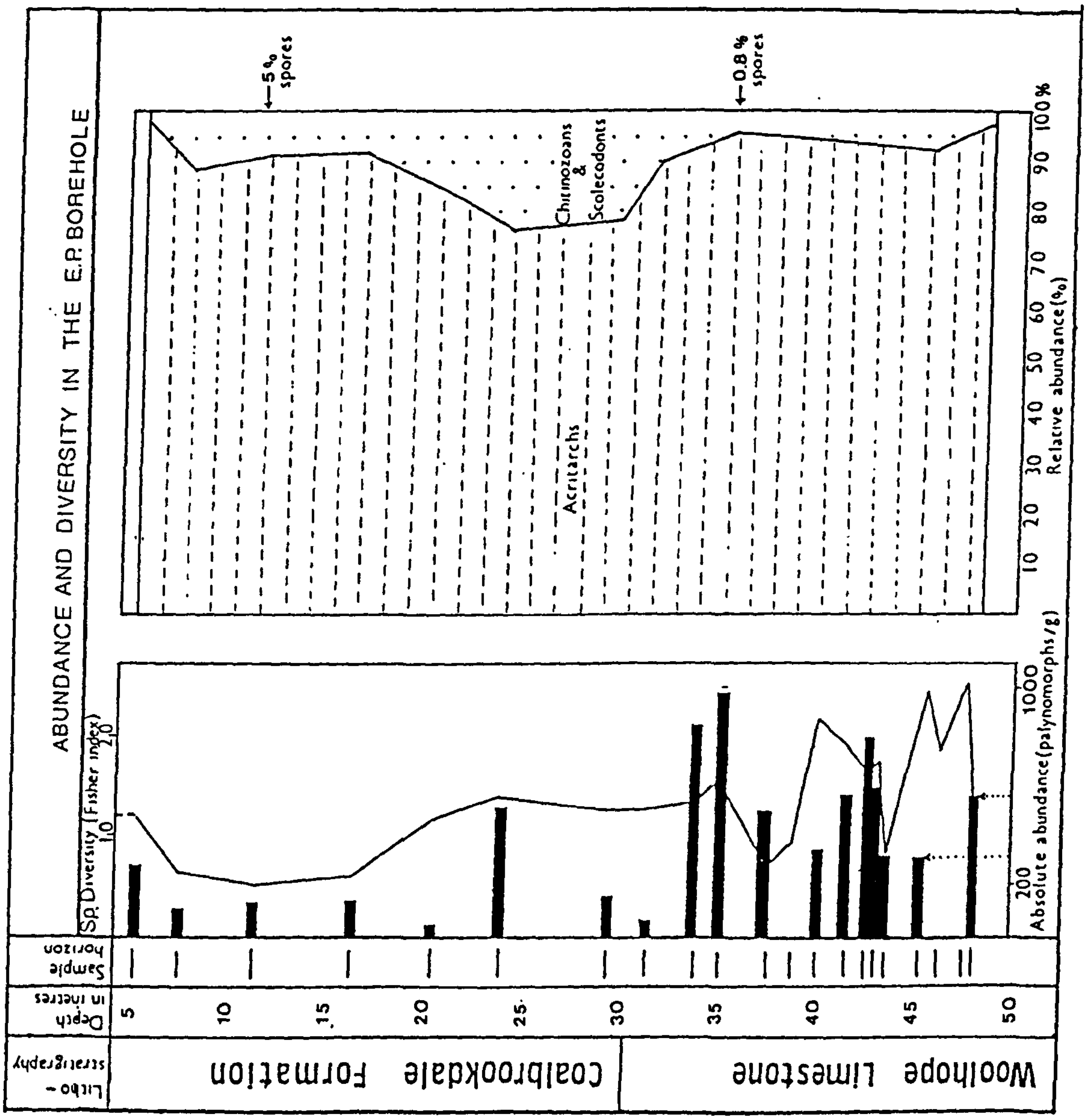


Fig. 15. Palynomorph absolute abundance and species diversity in the Eastnor Park Borehole.

borehole (and in the Malverns) and the interbedding of fairly pure limestone with calcareous siltstones and mudstones. For instance, the highest absolute abundance of palynomorphs in the section (992 palynomorphs/g) was recorded from a calcareous siltstone at 35.60m (sample MPA 28483) while the lowest abundance (316 palynomorphs/g) was recorded from a fairly pure limestone at 45.70-46.65m (KD/BS 2). Palynomorph abundance and diversity was not so variable in the Coalbrookdale Formation; both parameters are low to moderate through the section.

3.4.g. A comparison and contrast of palynomorph distribution with other sections

The top of the Woolhope Limestone in the Malverns has previously been correlated with the top of the Buildwas Formation of the Wenlock type area (see Bassett 1974, text-fig. 2).. This is supported by the biostratigraphy (Figs. 9,16) and also by absolute abundance variations (Figs. 8,15). In the three sections of the Eastnor Park borehole, the Lower Hill Farm borehole and the Whitwell Coppice section the lowest absolute abundance of the palynomorphs and a correspondingly low species diversity is seen in the transition from Woolhope Limestone and Buildwas Formation to Coalbrookdale Formation.

More supporting evidence for the correlation of at least part of the Woolhope Limestone (average absolute abundance 564 palynomorphs/g; average species diversity 16) with the Buildwas Formation (average absolute abundance 1448 palynomorphs/g; average species diversity 20) is that in both of these units palynomorph absolute abundance and species diversity is higher than in the overlying Coalbrookdale Formation. The Buildwas Formation and Woolhope Limestone Formation are thought to have been deposited in shallower water than the overlying Coalbrookdale Formation (Bassett 1974; Bassett et al. 1975; Hurst et al. 1978). A gradual deepening of the sea has been postulated from earliest Wenlock times until the latest Wenlock when shallowing led to the deposition of the Much Wenlock Limestone Formation. It is possible that the shallower water environments that led to the deposition of the Buildwas Formation and Woolhope Limestone were more suitable for microplankton proliferation, leading to high palynomorph abundances and to a greater species turnover and therefore higher diversities (the difference in palynomorph absolute abundance and species diversity between the Buildwas Formation and the Woolhope Limestone is linked to lithological and/or environmental differences, as discussed below).

Other fossil groups are also more abundant and diverse in the Buildwas Formation than in the overlying Coalbrookdale Formation of the Wenlock type area, including the brachiopods (Bassett et al. 1975; Bassett in Holland & Bassett 1989, p.63) and the conodonts (Bassett in Holland & Bassett 1989, p.65).

Absolute abundance in the Coalbrookdale Formation of the Eastnor Park borehole is an average 196 palynomorphs/g and species diversity is an average 11.5. The equivalent lower Coalbrookdale Formation of the Lower Hill Farm borehole (?140-199.14m) yields an average 718 palynomorphs/g and an average species diversity of 17.9. The considerable variation, although possibly related to real differences in the original assemblage (see Staplin 1961, p. 396-397; Jacobson 1979, p. 1209) may also reflect different lithologies; whereas the Coalbrookdale Formation (Apedale Member) in the Wenlock type area is a monotonous silty mudstone with only thin calcareous siltstones, in the Eastnor Park borehole the Coalbrookdale Formation consists of calcareous siltstones with impersistent bands of limestone. Differences are possibly related to an inverse relationship between number of palynomorphs and the amount of carbonate present in the studied sections, possibly related to different depositional rates with limestones being deposited faster than argillaceous lithologies (see Dorning & Bell 1987, p. 274). The relationship could also explain the differences in palynomorph absolute abundance and species diversity between the more argillaceous Buildwas Formation and the carbonate rich Woolhope Limestone. However this supposition does depend on phytoplankton cyst productivity being independent of substrate and as this cannot be proved the outcome is a circular argument.

Alternatively, or possibly in addition, contrasts in absolute abundances may also be due to differential compaction with siltstone being more readily compacted than limestone. Siltstones therefore may contain more palynomorphs per equal unit of rock.

The reasons that Staplin (1961, p. 396) listed for the acritarchs being generally much more abundant in off-reef (argillaceous sediments) than in near reef strata (carbonate sediments) are:-

1. Their optimum environment is the quiet, deeper water of the off-reef areas.

2. Wave action in shallower water near the reefs may have destroyed or winnowed out their remains.

3. Diagenetic processes might have destroyed the microfossils in the coarser, near-reef sediments.

4. Scavengers might have destroyed the organisms.

In conclusion, the Eastnor Park borehole, Lower Hill Farm borehole and Whitwell Coppice section show the previously recorded pattern of palynomorph distribution (Staplin 1961; Dorning & Bell 1987), with abundance and diversity apparently being indirectly proportional to the amount of carbonate present. The effect on the palynomorph assemblage could be environmental, depositional or due to different compactional rates. It is a possibility (even a probability) that all the factors had some effect.

Abundance and diversity fluctuations for the Eastnor Park borehole, Lower Hill Farm borehole and Whitwell Coppice section indicate that palynomorph abundance and species diversity were highest in the earliest Sheinwoodian (centrifugus Biozone), reached a low in the middle Sheinwoodian (murchisoni and riccartonensis biozones) and then increased to relatively higher and stable levels through the upper Sheinwoodian and lower Homerian (rigidus, linnarsoni, ellesae and lundgreni graptolite biozones).

A similar though not so obvious pattern can be observed in the Brinkmarsh Formation of the Tortworth area and to a lesser extent the Dolyhir Limestone of the Old Radnor area. The reason why the distribution pattern is not that obvious, is that in both of these sections palynomorph absolute abundance and species diversity is very low. The basinal sections are not suitable for comparison because the preservation of the palynomorphs in these sections is so poor that both abundances and species diversity have undoubtedly been affected.

3.4.h. Biostratigraphy (see Fig. 16, and appendix 2 summary log)

The interval in the Eastnor Park borehole from a depth of 50.10 to 42.10m (MPA 28416 to 28411) is characterized by the stratigraphical range of the acritarch species *Domasia quadrispinosa* Hill 1974b which is from 48.10-49.59 to 42.10m (KD/BS 1 to MPA 28411). Also within this interval are the first occurrences of the acritarchs *Gracilisphaeridium encantador* (Cramer 1970) Eisenack *et al*. 1973 at 47.80m (MPA 28415), *Estiastra barbata* Downie 1963 at 45.70-46.65 (KD/BS 2) and *Fractoricoronula checkleyensis* (Dorning 1981a) emend. at 42.10m (MPA 28411).

The interval above this from 39.60m to 35.60m (MPA 28410 to 28483) is characterized by the stratigraphical range of the zonal acritarch species *Deunffia furcata* Downie 1960 and also that of the chitinozoan *Salopochitina bella* Swire 1990. The presence of *Calpichitina (Densichitina) densa* (Eisenack 1962a) at 35.60m (MPA 28483) is also worth noting, as are the highest occurrences of the acritarchs *Gracilisphaeridium encantador* (Cramer 1970) Eisenack *et al.* 1973 at 39.60m (MPA 28410) and *Estiastra barbata* Downie 1963 at 35.60m (MPA 28483); the first occurrence of *Alveosphaera* ? *deflandrei* (Stockmans & Villière 1963) Priewalder 1987 is at 37.45m (MPA 28484). From 31.80m to 5.08m is another interval with a characteristic palynomorph assemblage defined by the first occurrence of the acritarch *Helosphaeridium malvernensis* Dorning 1981a at 31.80m (MPA 28481) and the chitinozoan *Cingulochitina cingulata* (Eisenack 1937) at 29.50m (MPA 28480). Within this interval also are the highest occurrences of the acritarch species *Salopidium woolhopensis* Dorning 1981a at 24m (MPA 28479), *Fractoricoronula checkleyensis* (Dorning 1981a) emend. at 20.20m (MPA 28478) and *Alveosphaera* ? *deflandrei* (Stockmans & Villière 1963) Priewalder 1987 at 11.70m (MPA 28476).

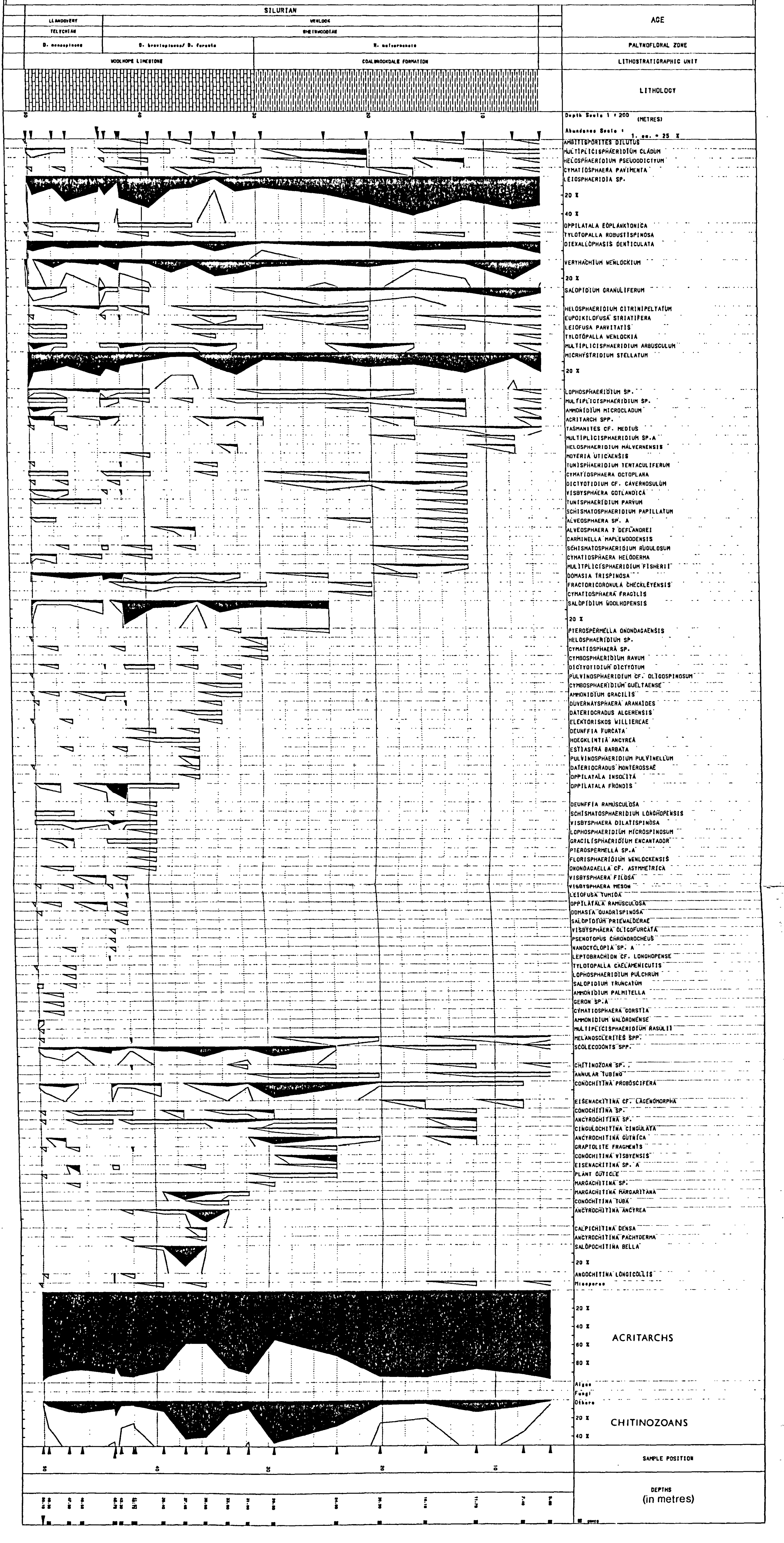
3.4.i. Correlation of the Eastnor Park borehole with the Lower Hill Farm borehole of the Wenlock type area

The interval from 50.10m (MPA 28416) to 42.10m (MPA 28411) does not correlate to any part of the studied section from the Lower Hill Farm borehole. First occurrences of the acritarchs *Gracilisphaeridium encantador* (Cramer 1970) Eisenack *et al.* 1973 and *Estiastra barbata* Downie 1963 in this interval, plus the restricted stratigraphical range of the acritarch *Domasia quadrispinosa* Hill 1974b, would seem to indicate a late Llandovery

EASTNOR PARK BOREH

FIGURE NO. 16

Normalized Palynological frequency diagram for the B.G.S. EASTNOR PARK BOREHOLE, HEREFORD AND WORCESTER



(Telychian) age for at least this part of the Woolhope Limestone (see Mabillard & Aldridge 1985, text-fig. 3).

Mabillard (1981) in an unpublished thesis suggested that in a studied section at Birches Lane Farm in the Malverns where a similar section to that seen in the Eastnor Park borehole is exposed, the presence in particular of the ostracods Menoeidina lavoiei and Hemiaechminoides monospinus in the lowest Woolhope Limestone also indicates a Llandovery age. The lowest Woolhope Limestone therefore probably approximates to the crenulata graptolite Biozone.

The interval in the Eastnor Park borehole from 39.60m (MPA 28410) to 35.60m (MPA 28483), correlates with the Buildwas Formation of the Lower Hill Farm borehole (from 234.57-236.07m; MPA 26083 to 203.12-204.65m; MPA 26076); this is based on the stratigraphical range of the zonal acritarch Deunffia furcata Downie 1960 (see p.61) which occurs in both boreholes. This interval is equivalent to the centrifugus and murchisoni graptolite biozones.

The interval from 31.80-29.50m (MPA 28481-28480) to 5.08m (MPA 28474) in the Eastnor Park borehole correlates approximately with the interval 199.14m to 160m in the Lower Hill Farm borehole (the lower Coalbrookdale Formation), based on the first occurrence of the zonal acritarch Helosphaeridium malvernensis Dorning 1981a (at 31.80m; MPA 28481) and the zonal chitinozoan Cingulochitina cingulata (Eisenack 1937) (at 29.50m; MPA 28480) and the highest occurrences of the acritarch species Salopidium woolhopensis Dorning 1981a at 24m (MPA 28479), Fractoricoronula checkleyensis (Dorning 1981a) emend. at 20.20m (MPA 28478) and Alveosphaera ? deflandrei (Stockmans & Willière 1963) Priewalder 1987 at 11.70m (MPA 28476). This interval is equivalent to the murchisoni, riccartonensis and rigidus graptolite biozones.

3.5. Graphical correlation

Because of the completeness of the studied borehole sections and the regular and accurately recorded sampling intervals, a method can be used which illustrates 'graphically an expression of correlation', after a technique described and illustrated by Shaw (1964). This takes into account common intervals in sampled sequences that display similar assemblages of fossils; the fossils ideally have short stratigraphical ranges.

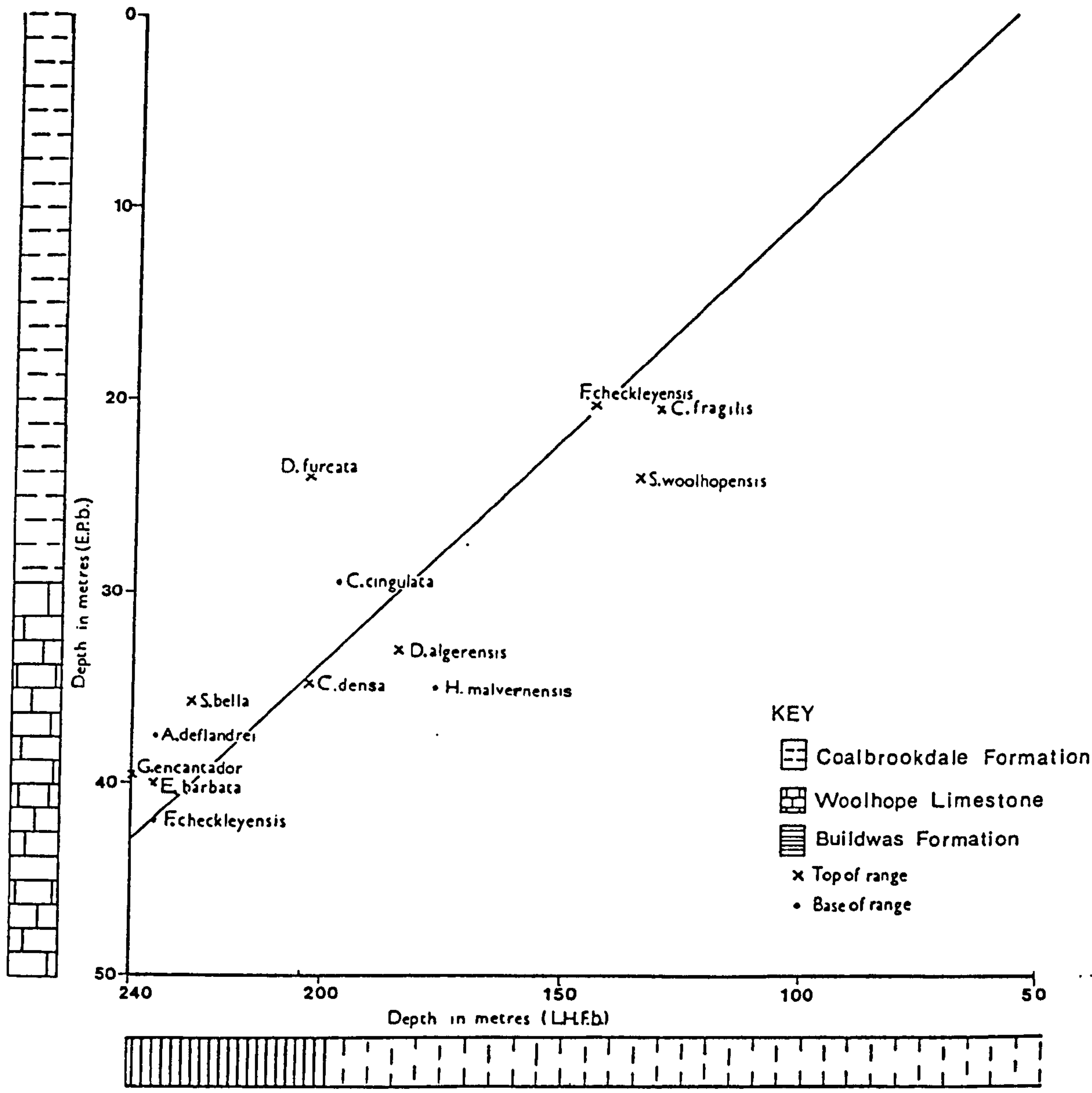


Fig. 17. Graphic-representation of the Eastnor Park borehole plotted against the Lower Hill Farm borehole.

In Fig. 17 the Eastnor Park borehole is plotted on the Y-axis, while the Lower Hill Farm borehole is plotted on the X-axis. The point from which the two boreholes are correlated is the base of the Woolhope Limestone in the Eastnor Park borehole at a depth of 50.10m (MPA 28416) and the base of the Buildwas Formation in the Lower Hill Farm borehole at 239.14-239.66m (MPA 26084). Wherever possible, both the first and highest occurrences of a species are plotted against each other for both boreholes; if this is not possible, then a species first or highest occurrence is plotted as a single point.

The line of best fit for the two boreholes is a line which crosses the Y-axis (the Eastnor Park borehole) at approximately 43m. The implication (which is already supported by the biostratigraphy) is that at least 7m of sediment (the base of the Woolhope Limestone) was deposited in the Malvern area before initial deposition of the Buildwas Formation in the Wenlock type area took place. This supports the proposition that the basal Woolhope Limestone is of late Llandovery (Telychian) age.

3.6. The Tortworth Inlier, Gloucestershire

Curtis (1955) described the Llandovery and Wenlock strata of the Tortworth inlier and summarized earlier work. He later (Curtis 1972) assigned the Wenlock rocks in the inlier to a single stratigraphical unit, the Brinkmarsh Beds (now the Brinkmarsh Formation), which comprise approximately of 244m of shales, mudstones, siltstones, and calcareous sandstones, with some impersistent limestones (Fig. 18). The best exposures are in the south-west of the inlier, south of Whitfield; here are three prominent limestones, at the base, near the middle and at the top of the succession respectively (Curtis 1972, pp. 20-21 and fig. 3). Lying just above the basal limestone is a distinctive horizon, the Pycnactis Band, this consists of some 3m of maroon-red shales and siltstones and has a rich coral/brachiopod fauna (Bassett 1974, p. 762; Hurst et al. 1978, p. 216); none of the faunas recovered from the Wenlock of Tortworth give any precise indication of their age (Hurst et al. 1978, p. 208).

The general aspect of the fauna and lithology in the Tortworth area suggests deposition in shallow off-shore waters (Siveter et al. 1989, p. 17). Few sedimentary structures have been found, but in the sandy beds at the top of the succession, ripple-marks, small-scale current-bedding and small drag-marks have been observed (Curtis 1972, p. 19).

3.6.a. Sampling localities (see Fig. 19)

The best exposure of the Brinkmarsh Beds in the area is in Brinkmarsh Quarry (SO 6736 9188). A detailed description of part of Brinkmarsh Quarry, which is the type locality of the Pycnactis Band was given by Reed & Reynolds (1908, p. 525). Five samples were collected from the north-western and southern parts of the quarry. The beds dip at 15° to the south west.

Samples 1-5. (BR/PS 1-5). Brinkmarsh Quarry

Collected from the lower limestone in the north-west and south of the quarry. The sampling interval is 1m.

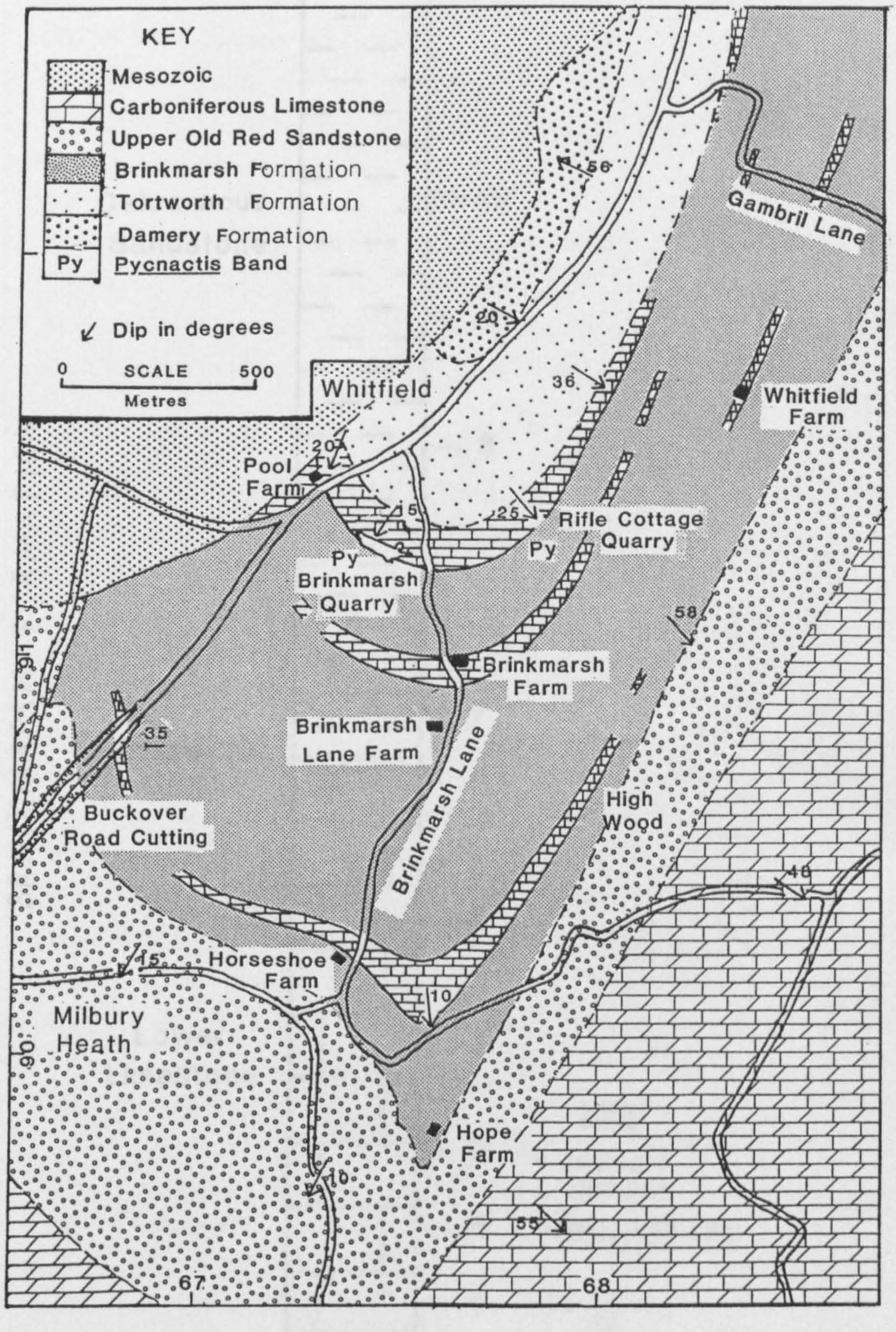


Fig. 18. Geological map of part of the Tortworth inlier, Gloucestershire (after Curtis 1972).

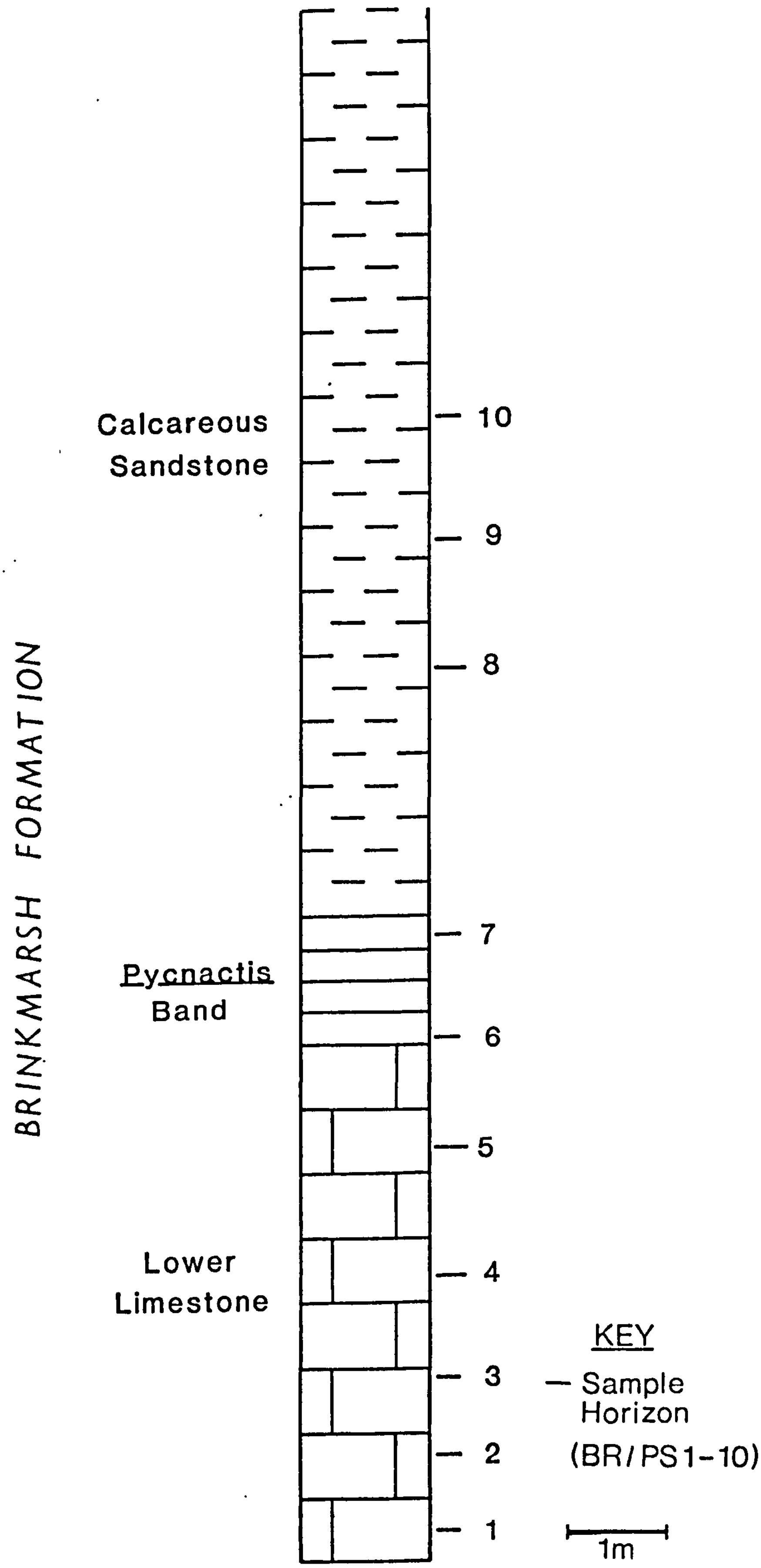


Fig. 19. Lithological section at Brinkmarsh Quarry and Lane, Tortworth inlier Gloucestershire.

Samples 6-7. (BR/PS 6-7). Brinkmarsh Quarry

Sample BR/PS 6, a maroon-red shale, was collected from the base of the *Pycnactis* Band exposed in the south of the quarry, sample BR/PS 7, a calcareous siltstone, was collected from 1m above this.

Samples 8-10. (BR/PS 8-10). Brinkmarsh Lane (SO 6739 9067)

Three samples collected at 1m intervals from calcareous sandstones exposed by the roadside 146m north-north-west of Brinkmarsh Farm. The sandstones lie stratigraphically above the lower limestone and *Pycnactis* Band (see Curtis 1972, fig.3).

3.6.b. Palynomorph distribution in the studied section

Absolute abundance (range 0.03-1.14 palynomorphs/g; average 0.27 palynomorphs/g) and species diversity (range 0.35-3.8; average 1.31) through the section are illustrated in Fig.20; although both are low, the preservation of recovered material is good.

The lowest abundance and diversity were recorded in a sample from the lower limestone (BR/PS 3); the highest abundance was also recorded in the lower limestone (BR/PS 4). The highest diversity was recorded from the stratigraphically higher calcareous siltstones (BR/PS 10).

The most abundant palynomorphs in the section are large thin-walled leiospheres (*Leiosphaeridia laevigata* Stockmans & Willière 1963) and small *Michrystridium* spp; other acritarchs are uncommon and chitinozoans are very rare. Small thin-walled scolecodonts were recovered in low numbers from three samples (BR/PS 1,9,10).

The link between the large thin-walled leiospheres (possibly algal spores?) and algae is a possibility as it has been noted that some of the limestones are partly algal in origin with *Rothpletzella gothlandica* being recorded from Brinkmarsh Quarry (Curtis 1972, p.18). Application of the Inshore Index (see p.82) supports a shallow water depositional environment for the Brinkmarsh Formation. Spores were not found in any of the samples, even though they were recovered from other localities in the Welsh Borderlands (which are presumed palaeoenvironmentally to be more offshore). Plant cuticle, annular tubing and other organic debris are also rare. As the sediments are presumed to have been deposited close to a shoreline, then there must be an explanation for the paucity of terrestrially derived

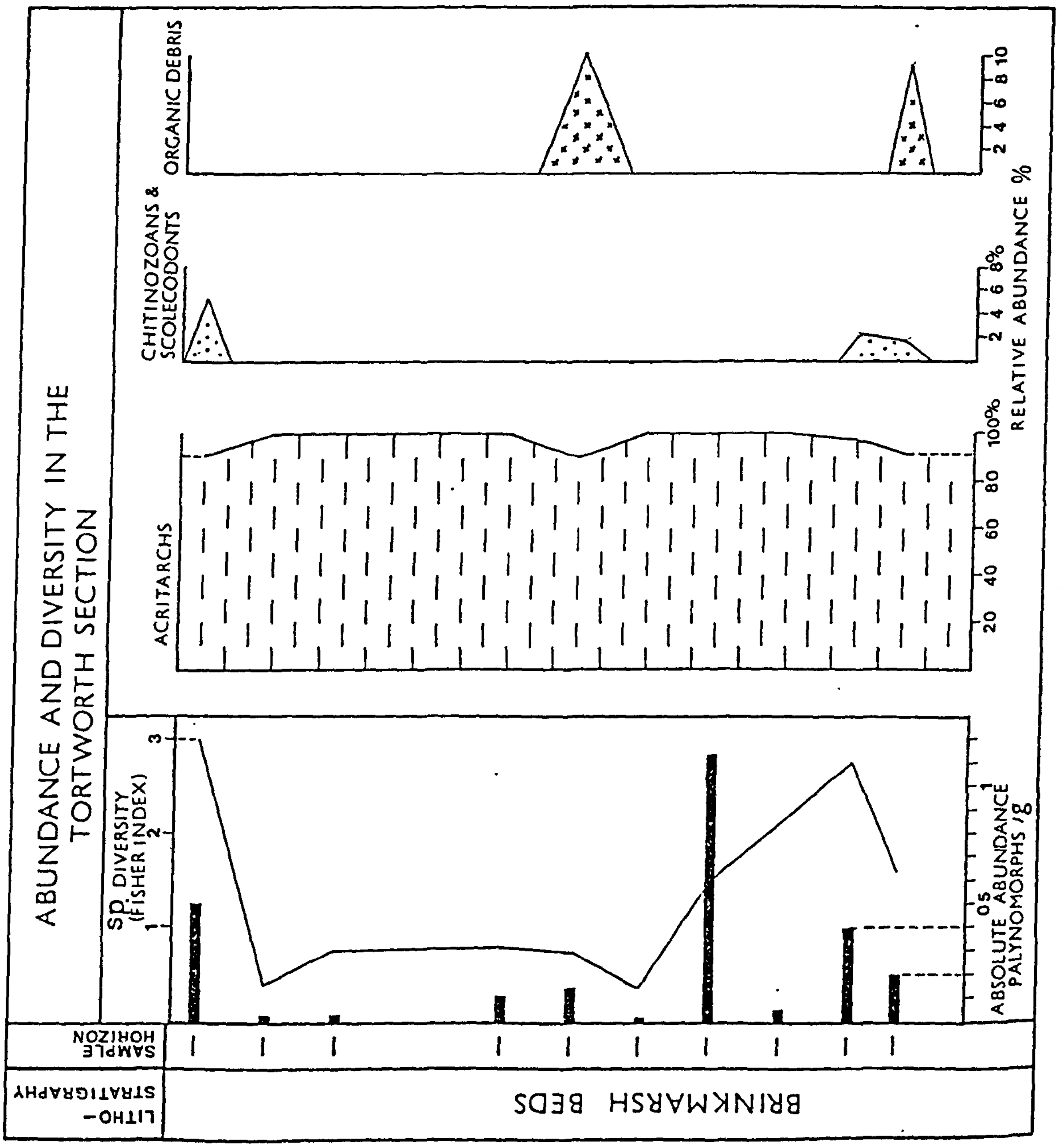
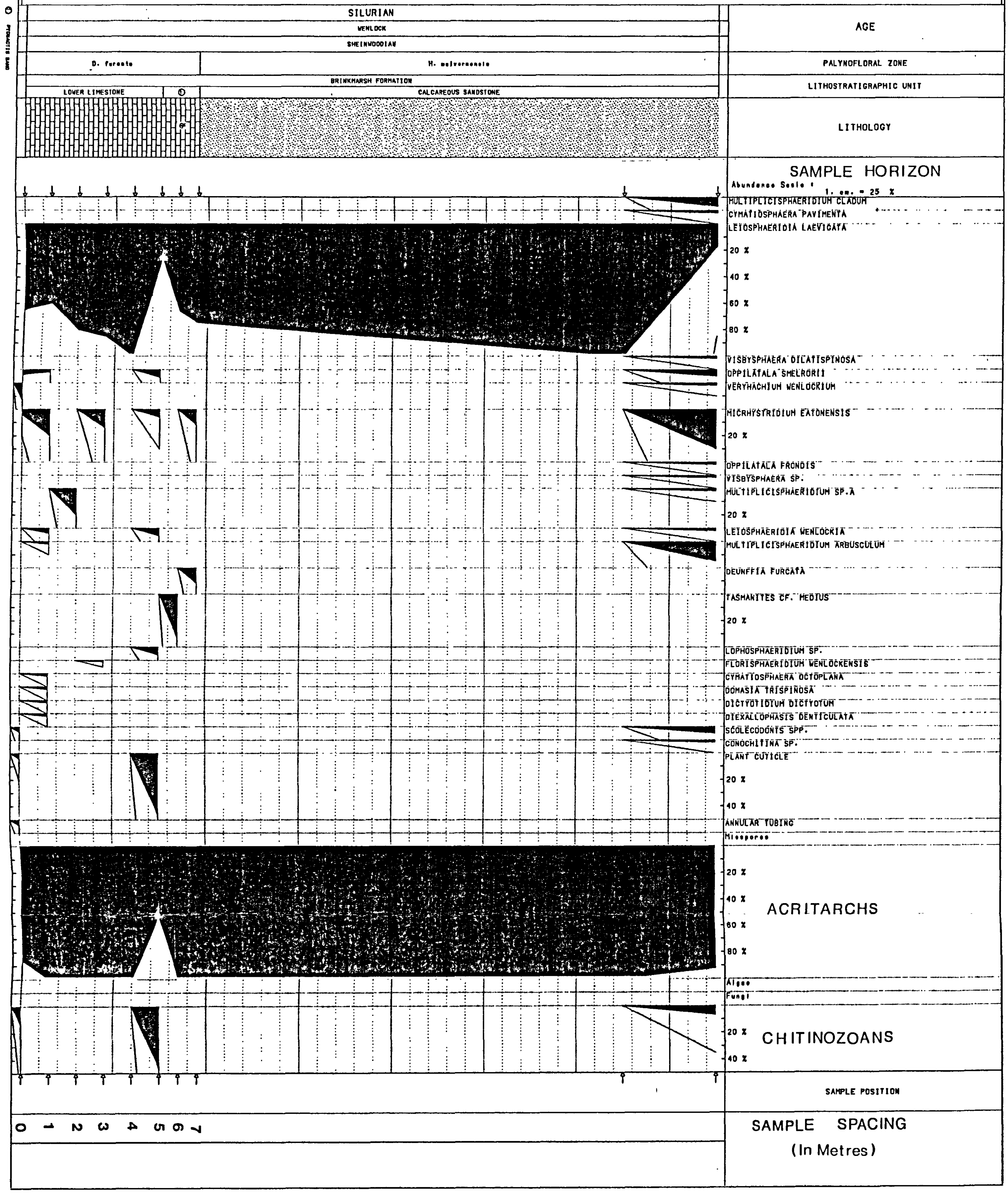


Fig. 20. Palynomorph absolute abundance and species diversity in the Tortworth section.

TORTWORTH INLIER

FIGURE NO. 21

Normalized Palynological frequency diagram for the SECTION FROM THE TORTWORTH INLIER GLOUCESTERSHIRE



organic material that was recovered. One possibility is that there were probably no local rivers issuing into the sea in the area (a prime source of terrestrial material). Another possibility is that strong offshore currents removed terrestrially derived organic material away from the shore, although there is no recorded sedimentological evidence for this in the sampled horizons. The only other explanation is that the land area adjacent to the site of deposition of the Brinkmarsh Formation had not been colonised by plants; it has to be remembered that land plants in the early Wenlock were very simple and very small and probably required special conditions in which to proliferate (Richardson & Edwards 1989).

3.6.c. Biostratigraphy (see Fig. 21)

The presence of *Deunffia furcata* Downie 1960 in sample BR/PS 7 (from the *Pycnactis* band) correlates to between a depth of between 234.57-236.07 (MPA 26083) and 203.12-204.65m (MPA 26076) (the lowest and highest occurrences of *Deunffia furcata* Downie 1960) in the Lower Hill Farm borehole and indicates that at least the *Pycnactis* band and most likely the lower limestone as well are correlatives of the Buildwas Formation (early Sheinwoodian) of the Wenlock type area (the *Deunffia furcata* Biozone).

The stratigraphically highest sample (BR/PS 9) from the calcareous sandstone exposure on Brinkmarsh Lane yielded an assemblage including the acritarch *Cymatiosphaera pavimenta* (Deflandre 1945) Deflandre 1954, it correlates to a depth no higher than 166.52m in the Lower Hill Farm borehole (the highest occurrence of *Cymatiosphaera pavimenta* (Deflandre 1945) Deflandre 1954, and therefore to either the Buildwas Formation or to the lower Coalbrookdale Formation of the Wenlock type area.

3.7. Dolyhir, Near Old Radnor, Powys (Central Eastern Wales)

In east Powys (Radnorshire), at Dolyhir near Old Radnor, the lower Wenlock succession is comprised of a thick development of massive, dark grey to white, crystalline algal and bryozoan limestone (Bassett 1974; Hurst et al. 1978). The average thickness of the limestone is about 24m. Garwood & Goodyear (1918) first described the limestone together with the structural complexity of this area and recent work on the structure has been undertaken by Woodcock (1988).

The basal unit of the Dolyhir Limestone consists of conglomerates and breccias which rest on shattered Pre-Cambrian (Longmyndian) grits, sandstones, mudstones, and dolerites (Garwood & Goodyear 1918; Bassett 1974; Siveter et al. 1989).

The limestone contains algae in the form of oncolites (Girvanella sp. and Sphaerocodium gotlandicum Rothpletz), stromatolites and other growth forms (e.g. Solenopora) (Hurst et al. 1978, p. 204). Other fossils are generally not common and are distributed patchily throughout the limestone. They include favositid corals, crinoids, bryozoans, brachiopods, trilobites and other groups (Garwood & Goodyear, 1918; Basset 1974, p. 759). The presence of algae indicates a very shallow turbulent environment, receiving little clastic sediment (Hurst et al. 1978).

It is thought that the limestone accumulated on a topographic high near the intersection of the Church Stretton fault and the margin of the Welsh basin (Woodcock 1988).

At Dolyhir overlying shales and siltstones belonging to the Coalbrookdale Formation are faulted against the limestones, preventing a firm stratigraphical assessment of original age relationships (Garwood & Goodyear 1918, p.23). Although later Kirk (1951a, p. 56) did mention that 'the limestone is overlain by mudstones with Cyrtograptus rigidus'.

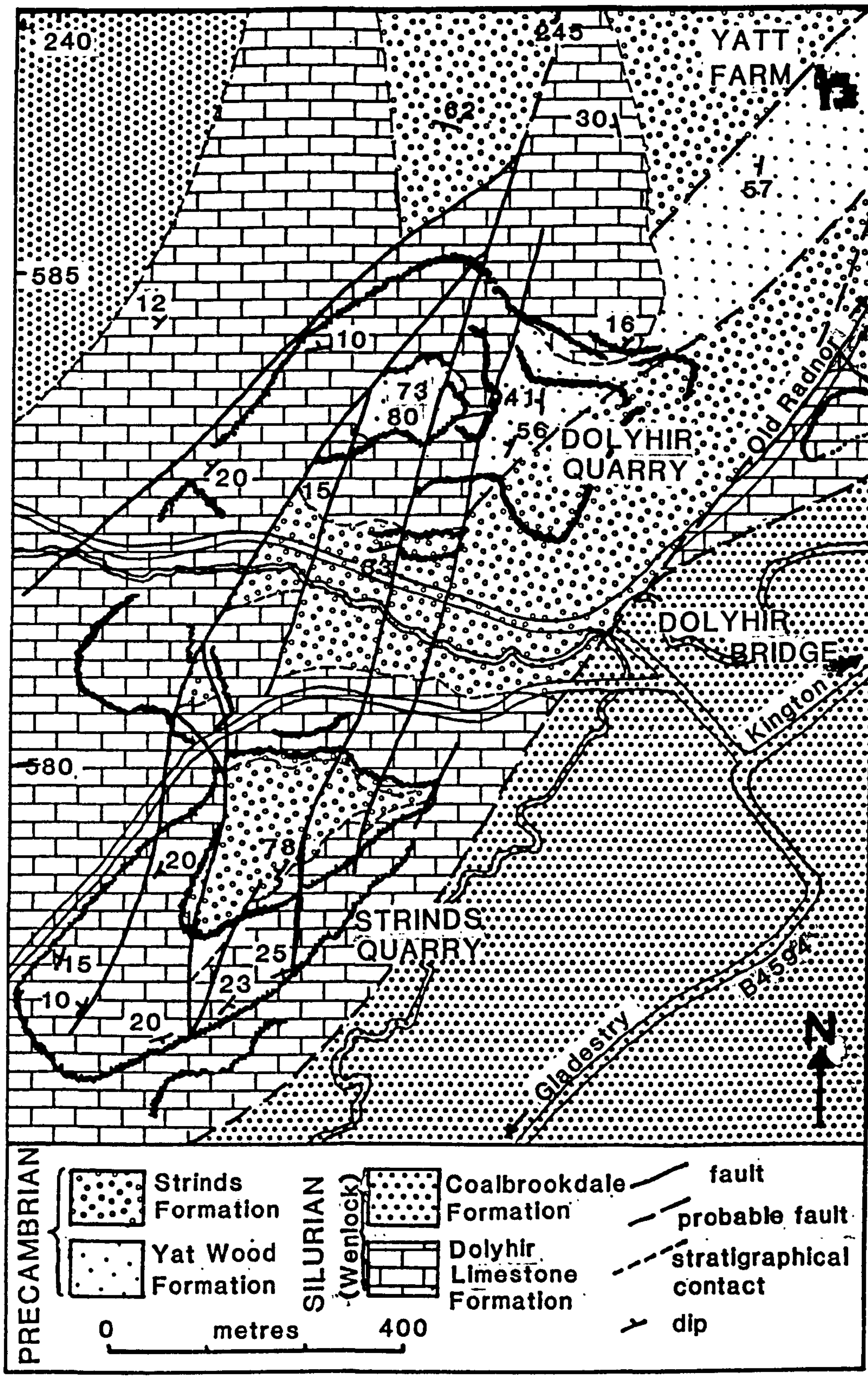


Fig. 22. Geological map of Strinds Quarry, Old Radnor (after Woodcock 1988).

3.7.a. Collected sequence (see Figs. 22 and 23)

Samples 1, 4-11.(DOL/PS1,4-11). North end of Strinds Quarry (SO 2450 5840)
Strinds quarry offers the best exposure in the area. Here the Dolyhir Limestone can be observed lying with strong angular unconformity on Precambrian sedimentary rocks (Strinds Formation). The Strinds Formation occupies the lower levels of the quarry, and consists of easily distinguishable 'pink and green greywackes and grits together with occasional bands of coarse conglomerate' (Garwood & Goodyear 1918, p.5). At the base of the limestone a rudite up to 2m thick is developed patchily; how well it is exposed depends upon the state of the quarry workings.

The collected lithology comprises a thick development of massive, dark grey to white, crystalline algal and bryozoan limestone. Sample 1 is from near the base of the limestone just above the rudite, samples 4-11 are at 2m intervals through the limestone. The section was collected from the south-west margin of the quarry near to the higher quarry road.

Samples 2-3.(DOL/PS2-3). (SO 2409 5812)
Collected from small old quarry by the side of a public road 475m WNW of Dolyhir bridge. Samples collected from a pocket of different lithology within the Dolyhir limestone, low down near the base. Sample 2 is a coarse bioclastic limestone and sample 3 is an overlying calcareous siltstone.

Samples 12-13.(DOL/PS12-13).
The olive grey siltstones of the Coalbrookdale Formation are faulted against the Dolyhir Limestone. One siltstone sample (12) was collected from a stream bank beneath the quarry road bridge (SO 2461 5820), another sample (13) was collected from a woodland copse 20m west of the stream (SO 2442 5800).

Sample 14.(DOL/PS 14). (SH 2445 5780)
Collected from an exposure of calcareous siltstone belonging to the Coalbrookdale Formation near Stockwell Farm. The siltstone contained fragmented brachiopods.

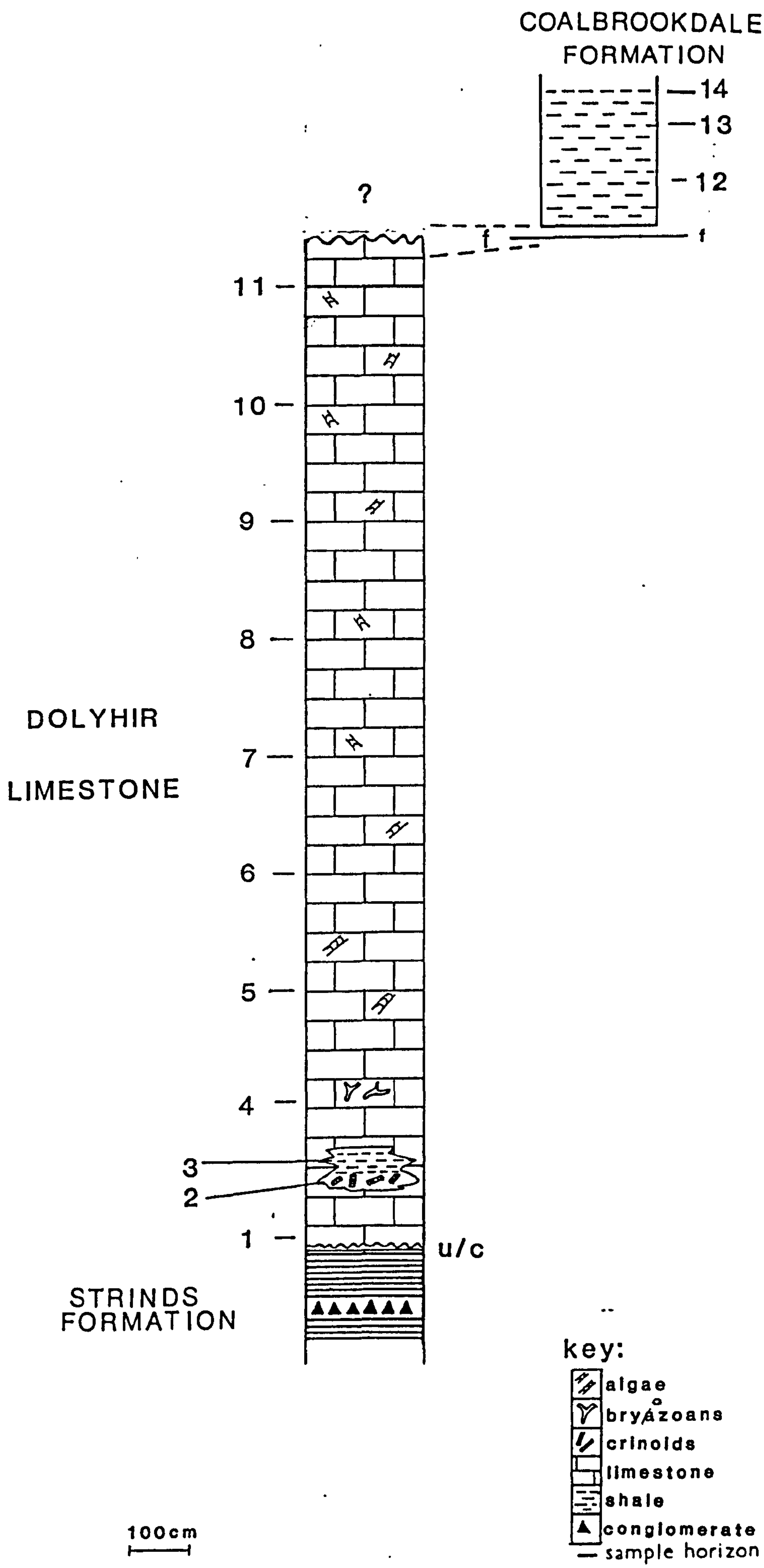


Fig. 23. Lithological section at Dolyhir.

3.7.b. Palynomorph distribution in the studied section

As Fig. 24 illustrates both species diversity (range 0.45-1.25; average 1.15) and absolute abundance (range 0.024-0.08 palynomorphs/g; average 0.057 palynomorphs/g) of palynomorphs is very low in the Dolyhir Limestone samples and is not very variable; even the sampled bioclastic pocket within the limestone (DOL/PS 2-3) did not yield a greater abundance of palynomorphs. Preservation of the material is good. The most abundant palynomorphs are large thin-walled leiospheres (*Leiosphaeridia laevigata* Stockmans & Willière 1963) and short-spined *Michrystridium* spp.; other acanthomorph acritarchs and chitinozoans are relatively uncommon; chitinozoans were only recovered from the basal two samples of the Dolyhir Limestone (DOL/PS 1-2).

Use of an Inshore Index (see p.82) on the Dolyhir limestone samples indicates that a shallow water depositional environment is most likely; the carbonate mound formed on a submarine high or possibly on an up-faulted island of Pre-Cambrian on the submarine slope (see Bassett 1974, p. 772; Hurst *et al*. 1978, p. 204). The presence of algae indicates a very shallow turbulent environment which received little clastic sediment; carbonate sediment derived from this shallow water area may have been transported into the adjoining deeper water areas (Hurst *et al*. 1978, p. 204).

It is possible that the environment of warm, shallow, algal rich waters in which the Dolyhir Limestone was deposited, were not appropriate for microplankton proliferation and that the only relatively numerous acritarchs (the thin-walled leiospheres) may infact be of algal origin themselves (algal spores, see Staplin 1961, p. 396). The low palynomorph abundance and species diversity though, may be linked with two more factors. It has been suggested that abundance of palynomorphs is indirectly proportional to percentage carbonate (Dorning & Bell 1987, p. 274) and that it is less in carbonate lithologies because of their comparatively rapid depositional rate. It is also probable that carbonates do not compact as well as shales and therefore the palynomorphs are more dispersed through the rock giving a lower abundance figure.

Curiously, species diversity (range 0.72-2.75; average 1.66) and absolute abundance (range 0.03-0.25 palynomorphs/g; average 0.16 palynomorphs/g) of palynomorphs is also low in the Coalbrookdale Formation, although it is a little higher than in the underlying Dolyhir Limestone. In

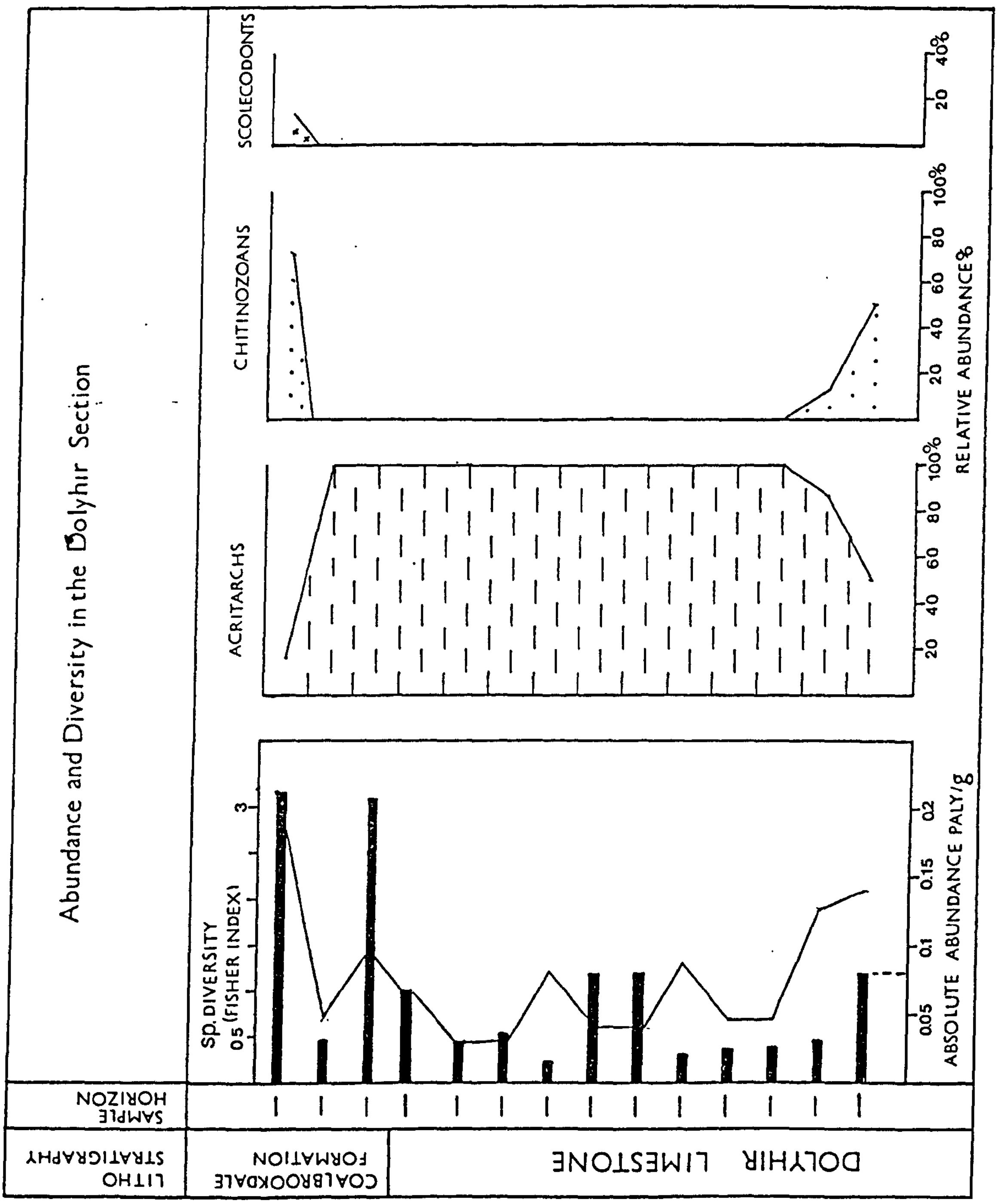


Fig. 24. Palynomorph absolute abundance and species diversity in the Dolyhir section.

contrast to the palynomorph assemblage from the Dolyhir Limestone, chitinozoans are more numerous and leiospheres and Michrystridium spp. are not so common.

It is possible that the Coalbrookdale Formation here is a deeper water (outer neritic) facies than that outcropping in the Wenlock type area and in the Malverns; this is probably related to the recorded early to mid-Wenlock transgressive phase in Wales and the Welsh Borderland, which finally flooded the low lying carbonate banks or islands that constituted the Dolyhir area. It is possible that the transgression was synchronous with subsidence in the area, possibly due to adjustments of the still active Church-Stretton lineament (Woodcock 1988). The result was deeper outer shelf waters that were not so suitable for microplankton proliferation (as were the shallower waters around the Wenlock type area); this is reflected in the lower palynomorph abundances and species diversity.

3.7.c. Biostratigraphy (see Fig. 25)

The palynomorph assemblage, in particular the occurrence of the acritarchs Helosphaeridium citrinipeltatum (Cramer & Diez 1972a) Dorning 1981a, Salopidium granuliferum (Downie 1959) Dorning 1981a and Ammonidium microcladum (Downie 1963) Lister 1970 and the chitinozoan Ancyrochitina gutnica Laufeld 1974, support a Wenlock age for the Dolyhir Limestone.

Although inconsistently present, the chitinozoan Cingulochitina cingulata (Eisenack 1937) has its first occurrence in the stratigraphically lowest sample from the Dolyhir limestone (DOL PS/1). Relating this to the Lower Hill Farm borehole (in the Wenlock type area) it correlates to no deeper than 199.14m, that is the lowest Coalbrookdale Formation which is indicative of the riccartonensis Biozone or younger.

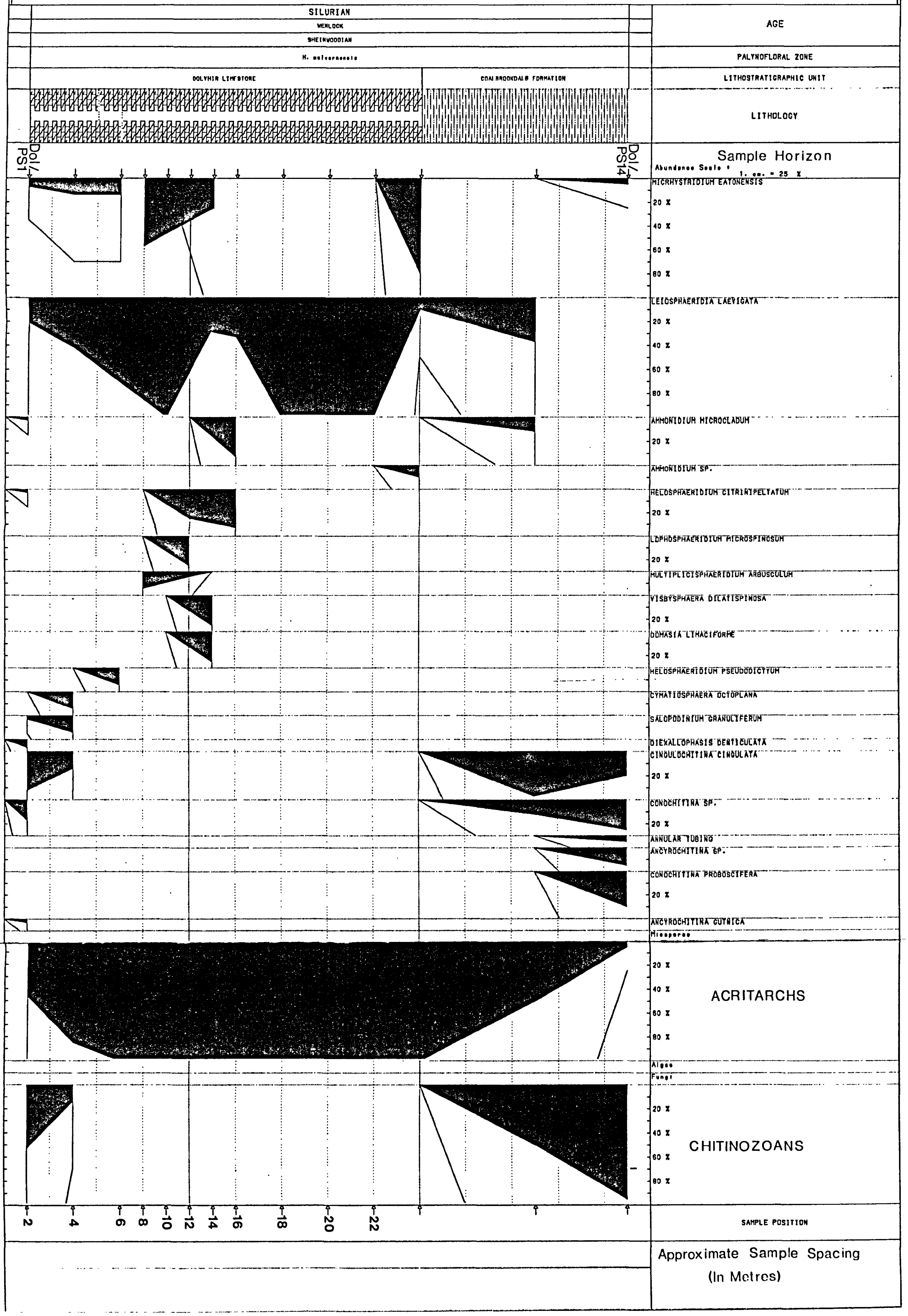
This is supported by conodonts recovered from the Dolyhir Limestone which indicate a saggita Conodont Biozone age, i.e. riccartonensis Biozone or younger (Bassett 1974, p759). The age is further restricted by the overlying Coalbrookdale Formation, which is faulted against the Dolyhir Limestone, and from which graptolites have been recovered that indicate a rigidus Biozone age (Kirk 1951, p.56).

Unfortunately stratigraphically useful acritarchs, other than those indicative of just a general Wenlock age, were not recovered from the three samples from the Coalbrookdale Formation (DOL PS/12-14).

DOLYHIR

FIGURE NO. 25

Normalized Palynological frequency diagram for the SECTION AT DOLYHIR, POWYS



3.7.d. Comparison with the shallow water sediments of the Tortworth area

The palynomorph assemblage from the Dolyhir Limestone is comparable with that recovered from the shallow water sediments of the Tortworth area. Both sections have significantly lower absolute abundances and species diversity than any of the other shelf sections. The average absolute abundance in the Dolyhir section (excluding the samples from the Coalbrookdale Formation) is 0.057 palynomorphs/g while from the Tortworth section it is 0.3 palynomorphs/g. Average species diversity is 1.31 for the Tortworth section and is 1.15 for the Dolyhir section. The palynomorph assemblage in both sections is dominated by thin-walled leiospheres (*Leiosphaeridia laevigata* Stockmans & Willière 1963) and short-spined *Micrhystridium* spp.; chitinozoans are of low abundance and diversity.

3.8. Pistyll Quarry, Nr Pant Y Dwr, Powys, (Central Eastern Wales)

3.8.a. Geological setting

The interface of facies in central eastern Wales (Powys) represents the late Ordovician-Silurian basin margin and largely lies across the Towy-Severn anticlinal structure (Fig. 26). At various times in its history, e.g. during the late Llandovery, this structure was active and had a strong influence over sedimentation. At other times such as in the Wenlock it appears to have been passive, but coincident with a slope (Dimberline & Woodcock 1987).

3.8.b. Pistyll quarry, nr Pant Y Dwr (SO 0093 7607) (Fig. 27)

A continuous section is exposed from the top part of the Tarannon Pale Shales into some 20m of the Nant-ysgollon Shales. The former are pale grey-olive mudstones, crumbly vaguely laminated (oxic, bioturbated muds) with at least one anoxic hemipelagite. Some 10m below the top they yield graptolites of the crenulata Graptolite Biozone (Roberts 1929). Above are several metres of grey mudstone in which thin layering and bioturbation including Chondrites burrows are present, representing a transition into the dark grey laminated mudstones of the Nant-ysgollon Shales, which are anoxic deposits containing much hemipelagite. They are referred to the centrifugus Graptolite Biozone (Roberts 1929).

The quarry exposure is important because it displays well a flip of 'oxicity' (oxic Tarannon Pale Shales to anoxic Nant-ysgollon Shales) and as an event is one of the fundaments of Lower Palaeozoic basinal deposition in this area (Dimberline & Woodcock 1987; Cave 1988).

3.8.c. Sampling horizons

Sample 1. (LRG/PS1). was collected from the top of the Tarannon Pale Shales which are Llandovery in age.

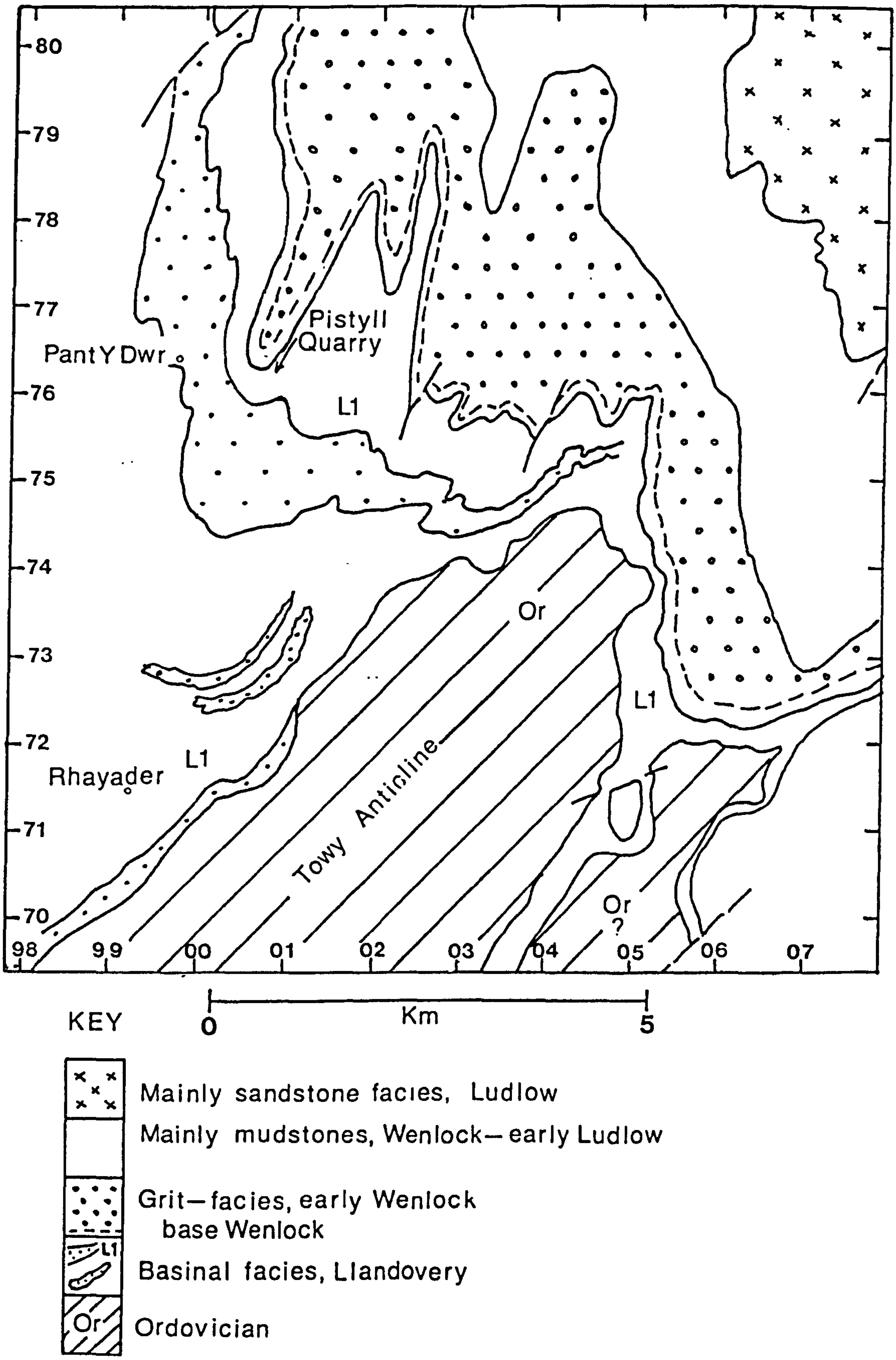


Fig. 26. Sketch of the geology of part of eastern Wales (Powys), based on BGS 1: 50,000 geological sheet 179.

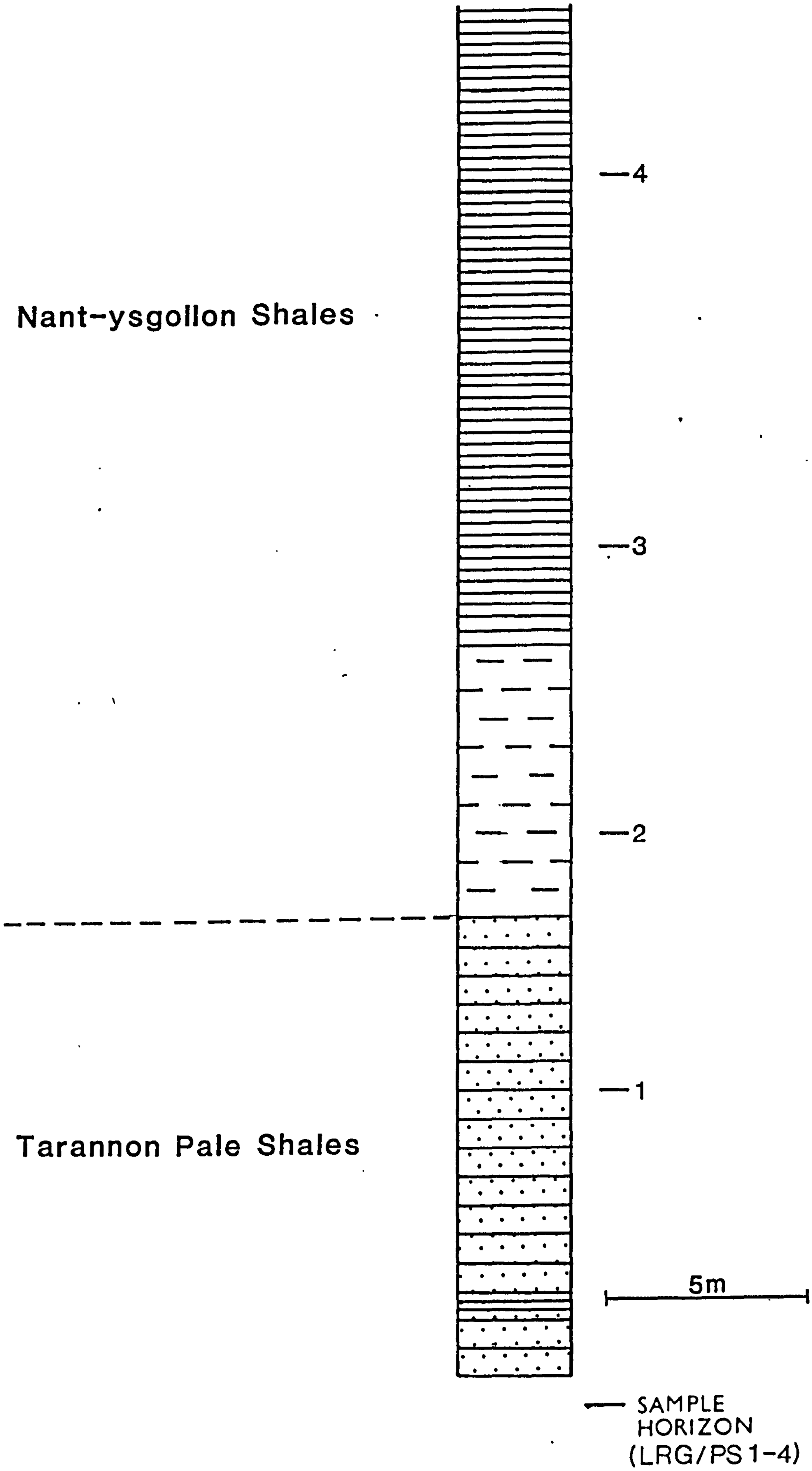


Fig. 27. Lithological section at Pistyll Quarry, eastern central Wales (Powys) (SO 0093 7607).

Samples 2-4. (LRG/PS2-4) were collected from the Nant-ysgollon Shales at intervals of approximately 3m through the section.

3.8.d. Material

Preservation of the recovered palynomorphs is generally poor, and thermal maturation correspondingly high. Palynomorph absolute abundance and species diversity are low. Average absolute abundance equals 2.78 palynomorphs/g (range 0-4.6 palynomorphs/g), average species diversity is 2.7 (range 2.1-7.1).

3.8.e. Acritarchs

The dominant palynomorph group is the acritarchs accounting for 94.5% of the total palynomorph assemblage. The dominant group represented is the sphaeromorphs which account for 85% of the acritarchs, both smaller thicker-walled and larger thinner-walled leiospheres were recovered; the former are more numerous. Absolute abundance varies between 0.13 and 4.6 acritarchs/g; it is lowest in the sample from the oxic bioturbated muds of the Tarranon Pale Shales and increases fairly dramatically in relative terms in the Nant-ysgollon Shales.

3.8.f. Chitinozoans and Scolecodonts

Chitinozoans account for 5% of recovered palynomorphs from the section, absolute abundance is low and varies between 0 and 0.35 chitinozoans/g. They were not recorded from two of the samples (LRG/PS 1 and 3).

Chitinozoans are only relatively common in one sample (LRG/PS 2), in this sample the taxon Sphaerochitina aff. sphaerocephala (Eisenack 1932) is particularly numerous.

Only two of the studied samples from the section yielded scolecodonts (LRG/PS 2,4). Absolute abundance is very low (0-0.02 scolecodonts /g).

3.8.g. Spores and Organic Debris

Trilete spores were not recovered from any of the samples. Organic debris in the form of annular tubing and Melanosclerites spp. was recovered in very low numbers from two samples (LRG/PS 2,3).

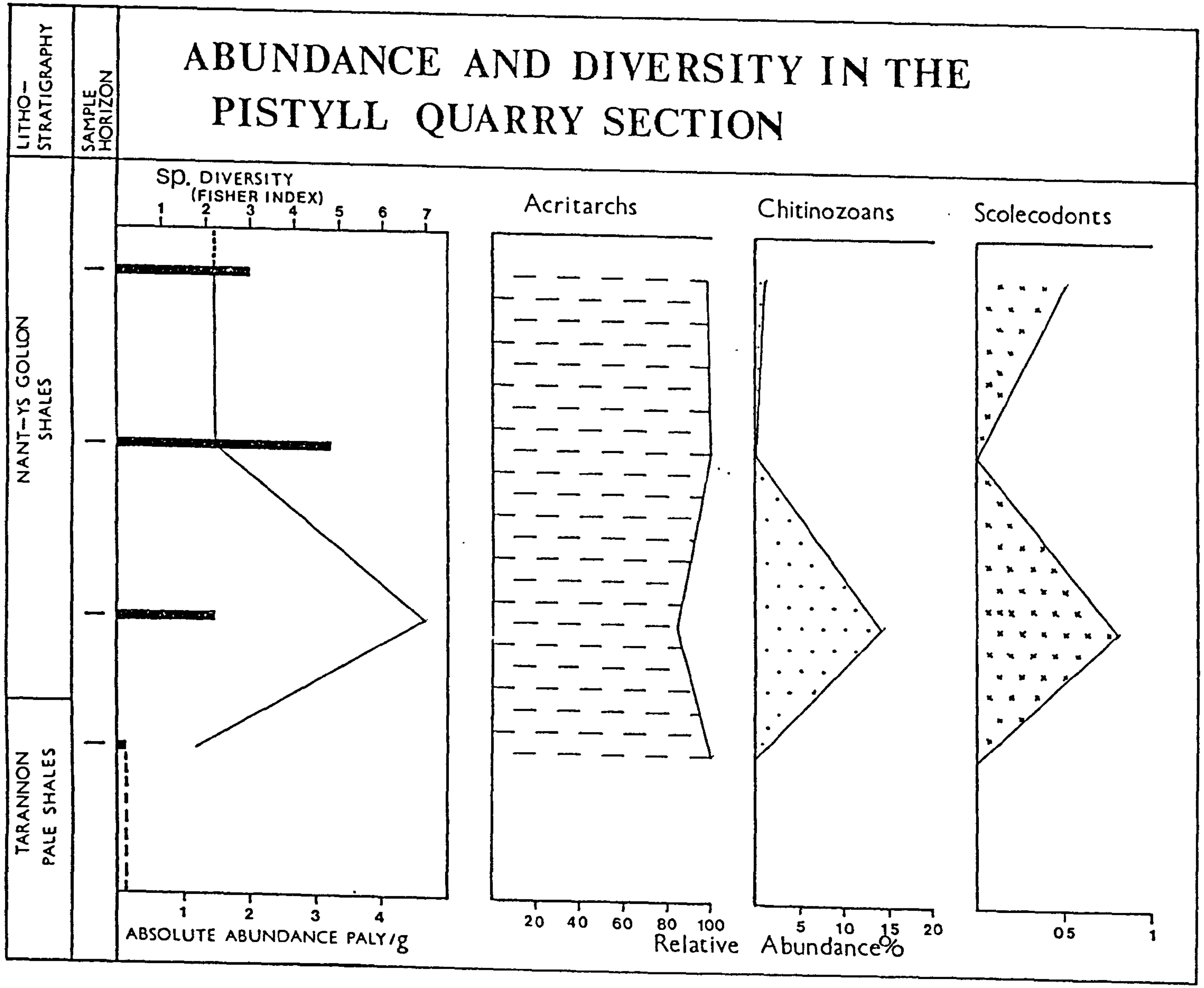
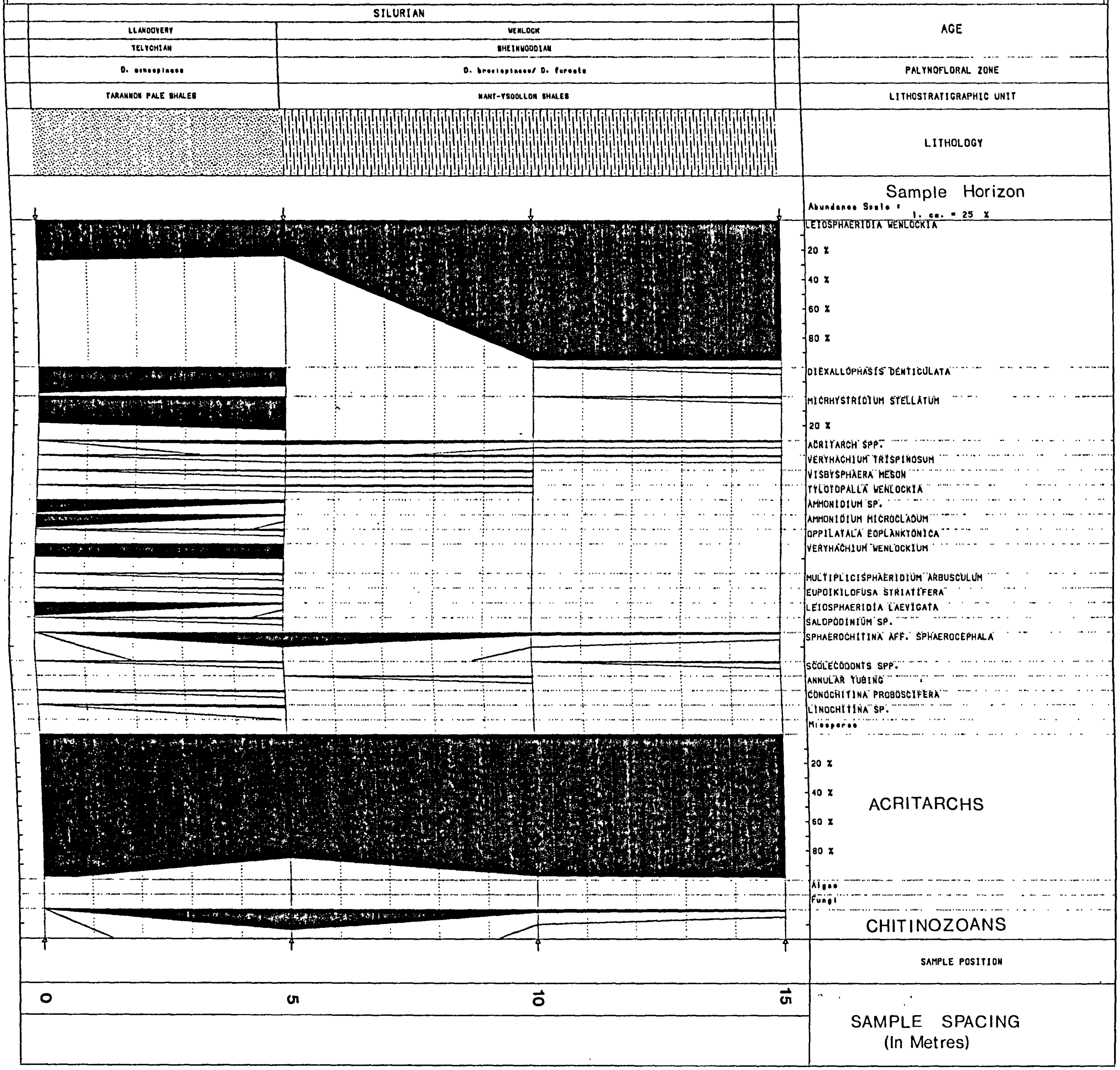


Fig. 28. Palynomorph absolute abundance and species diversity in the Pistyll Quarry section (Powys).

PISTYLL QUARRY

FIGURE NO. 29

Normalized Palynological frequency diagram for the SECTION AT PISTYLL QUARRY, POWYS



3.8.h. Comparisons and contrasts in the palynomorph distributions

Fig. 28 illustrates absolute abundance variations for palynomorphs in the section; abundance and diversity overall is low to moderately low, both are higher in the anoxic Nant-ysgollon Shales.

Because only four samples were studied from this locality it is difficult to undertake a detailed comparison with other studied sections. Broadly the absolute abundances, species diversity, preservation and composition of the palynomorph assemblage has more in common with the basinal samples of the Llanrwst and Conway sections, although both average absolute abundance and species diversity is notably higher in the Pistyll Quarry section.

3.8.i. Biostratigraphy (see Fig. 29)

Although none of the 'zonal' palynomorphs which would allow a high resolution correlation with the Wenlock type area were recovered from the Nant-ysgollon Shales of the Pistyll Quarry section (samples numbers LRG/PS 2-4), the occurrence of the acritarchs *Ammonidium microcladum* (Downie 1963) Lister 1970, *Visbysphaera meson* (Eisenack 1954) Lister 1970 and *Multiplicisphaeridium arbusculum* Dorning 1981a and the presence of the chitinozoan *Conochitina proboscifera* (Eisenack 1937) are consistent with the Nant-ysgollon Shales being of Wenlock age.

The sample from the underlying Tarranon Pale Shale did not yield any stratigraphically useful palynomorphs which would date it as being Llandovery rather than Wenlock in age.

3.9. <u>North Wales</u>

3.9.a. <u>Lithologies</u>

The Denbigh Grits Group and overlying Lower Nantglyn Flags Group outcrop along the sides of the Conway Valley; their thicknesses are up to 1100m and 625m respectively (Warren 1971) (Figs. 30 and 31). Most of the sequence is composed of sandstone, siltstone and mudstone, although there is also a small amount of carbonate rock (Warren et al. 1984). The sandstones, can more precisely be classified as greywackes (Pettijohn, 1957). Finer grained sediments can be subdivided into: striped silty mudstones, ribbon-banded mudstones and mottled mudstones (Warren et al. 1984). The striped silty mudstones are made up of of irregular alternations of silty mudstone and siltstone or fine sandstone, the ribbon-banded mudstones consist of regular alternations of thin bands (averaging 20mm) of silty mudstone and laminated muddy siltstone (see Boswell 1949, p. 41) and the mottled mudstones of irregularly cleaved and mottled, calcareous silty mudstones (see Boswell 1949, p.37). Some rocks display contorted and/or fragmented bedding, the strata are then referred to as disturbed beds (Jones 1937); it is thought that they are the products of penecontemporaneous subaqueous slumping or sliding.

Although the succession is rich in graptolites, they are almost entirely restricted to the laminated muddy siltstone units of ribbon-banded mudstone. There is also a shelly macrofauna composed of corals, bryozoans, brachiopods, gastropods, bivalves, cephalopods, trilobites, ostracods and crinoids (Cummins 1957, 1959). The components of this fauna are seen in all the rock types described, although the shelly fauna is mainly present in disturbed beds and in calcareous siltstones, which from their weathering characteristics, are referred to as 'gingerbread' horizons. It has been suggested that only in the mottled mudstones can the shelly fauna be considered autochthonous (Warren et al. 1984).

The geology of the area is comprehensively covered in a British Geological Survey memoir 'Geology of the country around Rhyl and Denbigh' (Warren et al. 1984). Included in the memoir is a preliminary palynological

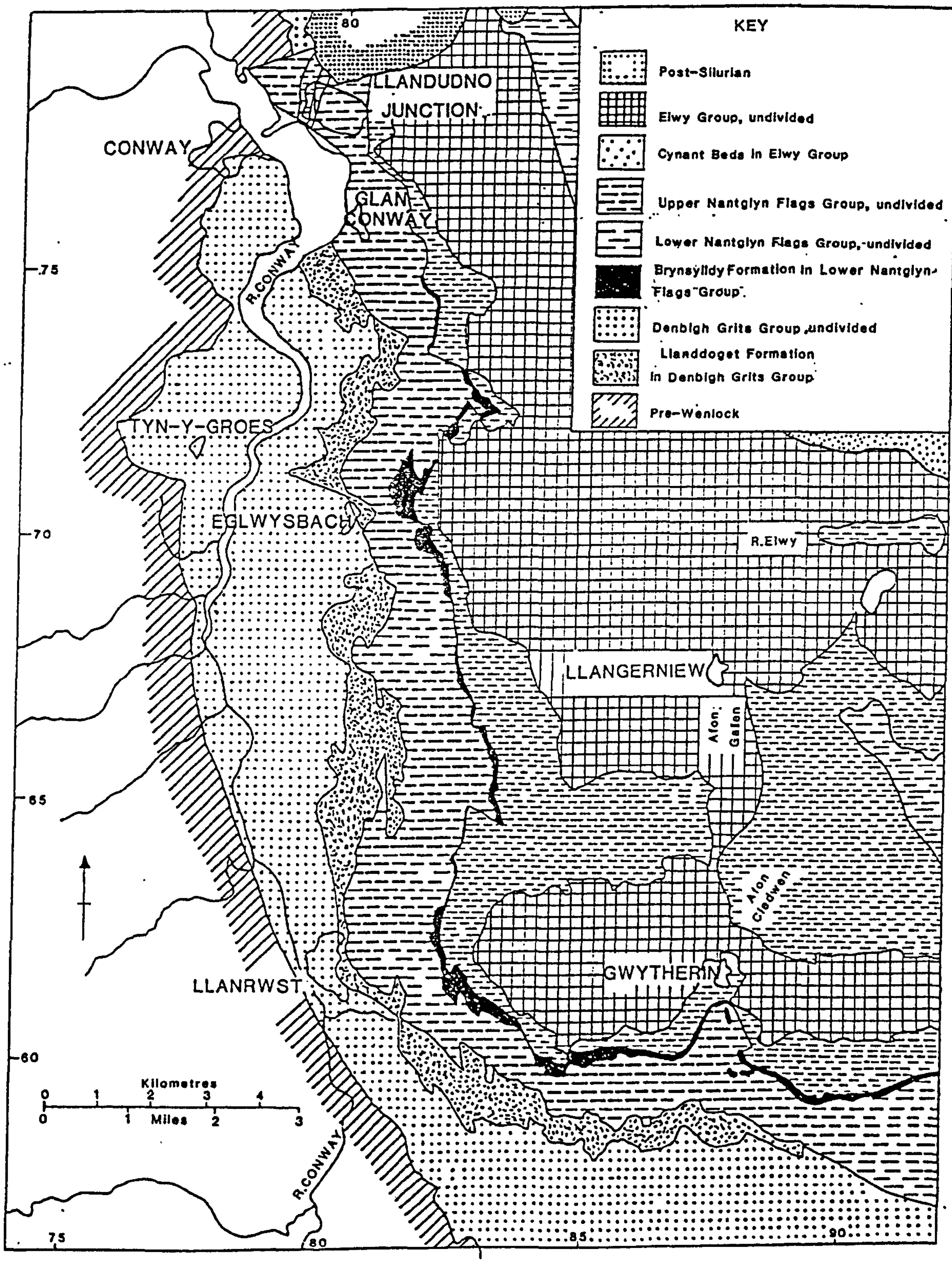


Fig. 30. Simplified geological map of the studied area North Wales (after Warren et al. 1984)

analysis which was undertaken by T. R. Lister on samples from the Denbigh Grits Group. The only other published palynological study in North Wales was carried out by Swanson & Dorning 1977, who reviewed the palynology of the Dinas Bran Beds (Whitcliffian age) of Llangollen in Clwyd.

3.9.b. Historical review

Murchison (1859) first used the term Denbigh(shire) Grits, the unit though had been recognised much earlier and was described under such terms as 'Denbighshire Sandstones' (e.g. Sedgwick 1844). Boswell (1949, p.35) shortened the Denbighshire Grit and Flag Series to Denbigh Grit Series, although previously he had used the even briefer term Denbigh Grits (1926, pp. 560-561); Cummins (1957) used the same terminology. Warren (1971) divided the Wenlock beds into two groups: the Denbigh Grits Group which ranges from the *centrifugus* Biozone to the *linnarssoni* (= *perneri*) Biozone, and the Lower Nantglyn Flags Group which ranges from the *linnarssoni* Biozone to the *ludensis* Biozone.

3.9.c. The studied sections

Two composite sections were collected from North Wales, one in the Llanrwst area (the Llanrwst region of Warren *et al*. 1984 p. 71-76) and one in the Conway area (including samples from the Benarth and Eglwysbach regions of Warren *et al*. 1984 p. 63-70). Twenty-seven samples were collected from the Llanrwst area and seventeen from the Conway area.

3.10. The Llanrwst composite section (see Fig. 32: rock sample documentation shown in brackets).

Samples 1-9. (CS/PS 1-9). Coed Soflan forestry track cutting, NW of Nebo (SH 8197 5772).

The collected beds consist of thinly interbedded dark grey silty mudstones, pale grey-green partly mottled mudstones, calcareous siltstones and ribbon banded mudstones. The base of the section was taken at a lithological change into pale green siltstones (the Llandovery Pale Slates), the sampling interval for the nine collected samples was 0.5m. Graptolites were recovered from a ribbon banded mudstone (sample CS/PS 3), one specimen being identified as *Cyrtograptus* sp.; a graptolite fauna has previously been

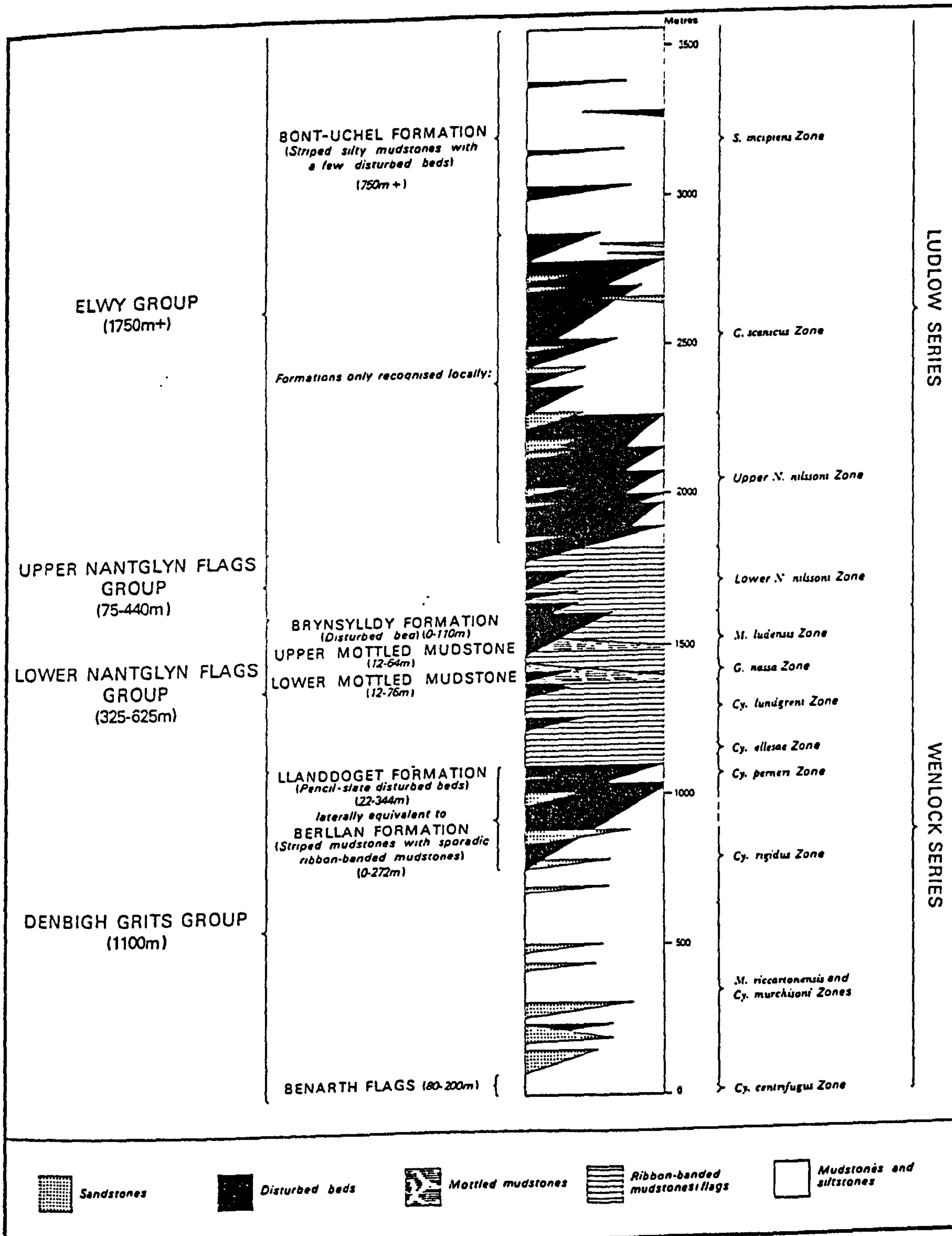


Fig. 31. Generalised section of the Wenlock-Ludlow rocks in North Wales (after Warren et al. 1984).

recovered from this locality, and is indicative of the *centrifugus* Biozone (Warren *et al*. 1984, p. 72).

Samples 10-12. (PEN/PS 1-3). Quarry exposure between Penrallt and Hendre house (SH 8151 5873).
16m of fine grained sandstone and siltstone with flutes and longitudinal ridge casts are exposed, three samples were collected at 2m intervals, the base being taken at a particularly coarse sandstone unit exposed at the foot of the quarry. Graptolites have previously been recovered placing this exposure in the *centrifugus* Biozone (Warren *et al*. 1984, p.72).

Sample 13. (HAF/PS 1). Hafotty Bach, section by stream due east of Hafotty by the roadside and 100m due south of the road (SH 8344 5844).
The sequence is of coarse grits succeeded by a repetitious sequence of thinly bedded silts and muds. The sample is from a mudstone which lies above a siltstone on the western side of the stream near a small waterfall. Previously recovered graptolites place this exposure in the *rigidus* Biozone (Warren *et al*. 1984, p.72).

Sample 14. (GAR/PS 1). Garth-Y-Pigau, exposure of ribbon banded silty mudstone in old quarry east of farm (SH 8264 5856). Graptolites have previously been recovered placing this exposure in the *rigidus* Biozone (Warren *et al*. 1984, p.72).

Sample 15. (CLY/PS 1). Clytiau-Teg, field exposure of dark banded silty mudstone (SH 8436 5838). Graptolites have previously been recovered placing this exposure in the *rigidus* Biozone (Warren *et al*. 1984, p.72).

Samples 16-24. (OER/PS 1-9). Oerfa quarry WSW of Bryn-Y-Gwynt (SH 8372 5881). Nine samples were collected from the Llanddoget Formation (samples 18-24) and the underlying Denbigh Grits (samples 16-17). No macrofossils have previously been recorded from the Llanddoget Formation in the Llanrwst region (Warren *et al*. 1984, p. 74).

The quarry exposes in descending stratigraphical order :-

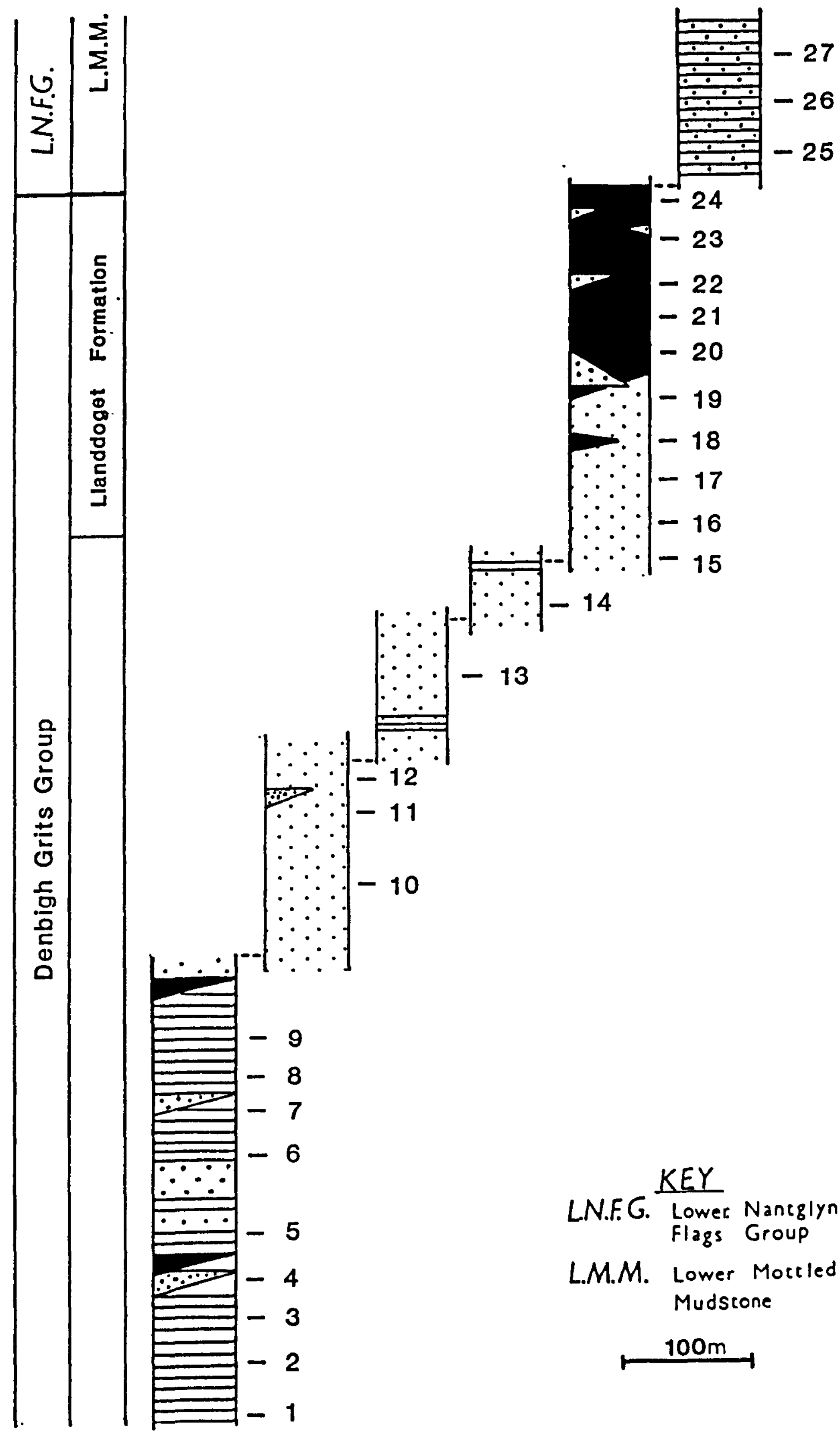


Fig. 32. Composite section in the Llanrwst area, North Wales.

4m Siltstone with coarse bands which pass south eastwards into medium-grained sandstones with lenses of quartz gravel and disturbed siltstone. Samples 19-24 (OER/PS 2-7) collected at 0.5m intervals through the siltstone.

4.5m Sandstone, medium-grained, with a few siltstone partings and thin lenticular bands of quartz gravel ('tapioca rock'). Sample 18 (OER/PS 1) collected from siltstone parting.

5.0-10.0m Disturbed bed, largely pencil slate mudstone; thins south-eastwards and passes into disturbed siltstones and sandstones with pebbles; base irregular. Sample 17 (OER/PS 9) collected from disturbed siltstone.

0.15-1.0m Conglomerate; well rounded pebbles, largely of vein quartz to 5cm in mudstone matrix, thickens south-eastwards to over 1m and passes into disturbed siltstone and conglomerate. Sample 16 (OER/PS 8) collected from disturbed siltstone.

c. 7.0m Conglomerate of fine quartz gravel in medium-grained sandstone matrix ('tapioca rock').

Samples 25-27. (BRA/PS 1-3). Coed-Y-Brain (SH 8168 6177)

Samples 25-26. (BRA/PS 1-2). Small gorge exposing the Lower Nantglyn Flags. Two samples were collected from an exposure of ribbon-banded silty mudstones, which vary from thin-bedded or flaggy to massive; concretions and local thin disturbed beds are present. Graptolites have previously been recovered placing this exposure in the *ellesae* Biozone (Warren *et al*. 1984, p.75).

Sample 27. (BRA/PS 3). Roadside exposure near gorge exposing irregularly fractured Lower Mottled Mudstone which weathers to a pale brown with goethite veinlets. A shelly fauna has previously been recorded from this exposure including a solitary coral, *Clorinda* sp., *Eoplectodonta* sp., *Dawsonocera annulatum*, *Kionoceras* sp., *Orthoceras* cf. *mocktreense*. and *Cryptocaris*[= operculum of *Orthotheca*] (Warren *et al*. 1984, p.75).

3.10.a. Material

Thermal maturation of the palynomorphs is high and preservation is poor, with many specimens damaged and fragmented. The absolute abundance for the section varies from 0-0.73 palynomorphs/g (average 0.16 palynomorphs/g) and the species diversity ranges from 0-4.8 (average 1.69).

3.10.b. Acritarchs

Acritarch absolute abundance is low (range 0-0.3 acritarchs/g; average 0.09 acritarchs/g). The acritarchs are generally more abundant in the finer grained shales than in the coarser grits. The only barren sample was that from the Lower Mottled Mudstone Member of the Lower Nantglyn Flags Group (sample 27; BRA/PS 3); this is the most carbonate rich sample, it contained only indeterminate and sparse organic fragments. The dominant acritarch group is the sphaeromorphs (mainly small thick-walled leiospheres; Leiosphaeridia wenlockia Downie 1959) which account for 56% of the assemblage. The acanthomorphs were moderately well represented accounting for 30% of the acritarchs encountered. Reworked Ordovician acritarchs were recovered including Ordoviciidium sp., Peteinosphaeridium sp., Striatotheca sp., and Frankea sp., they are never particularly common and are confined to the disturbed beds at Oerfa (samples OER/PS 3,8), and the mudstone at Hafotty-Bach (HAF/PS 1), both possibly slumped horizons.

3.10.c. Chitinozoans and scolecodonts

The chitinozoans are typically of moderate to low abundance (range 0-0.2 chitinozoans/g; average 0.057 chitinozoans/g) and are generally poorly preserved and fragmented, although in relative terms of the total recovered palynomorph assemblage they constitute their highest proportion (33%) in comparison to other sections (0.3%-26%). The chitinozoans are most common in the Lower Nantglyn Flags (samples 25,26; BRA/PS 1-2), where comparatively numerous large conochitinids are apparently associated with correspondingly large scolecodonts.

No spores were encountered in any of the samples, although scattered and sparse organic debris in the form of Melanosclerites spp. and annular tubing was recorded throughout the section.

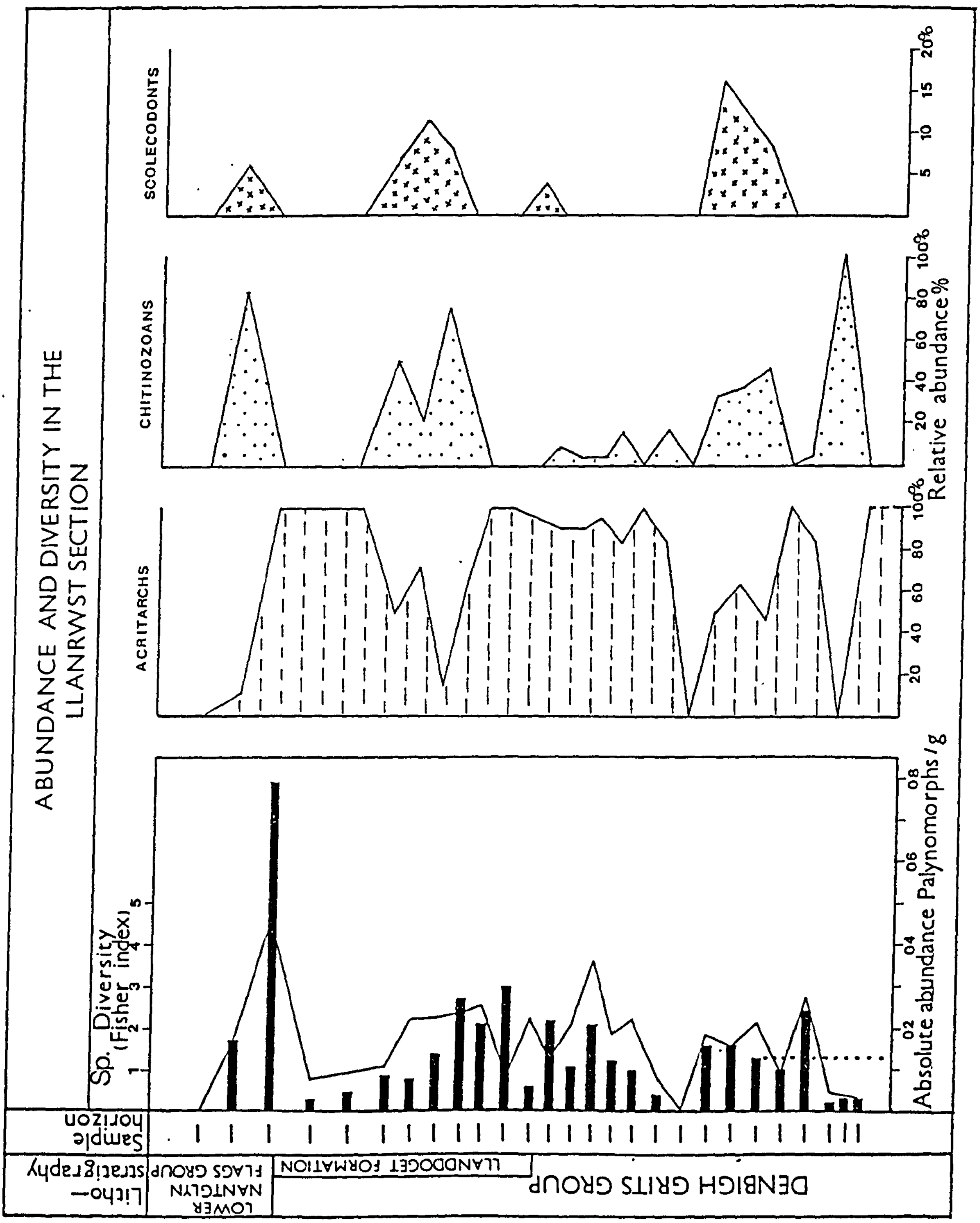


Fig. 33. Palynomorph absolute abundance and species diversity in the Llanrwst section.

3.10.d. Palynomorph distribution through the section

Fig. 33 shows that palynomorph absolute abundance (average 0.15 palynomorphs/g) and species diversity (average 2.1) in the Denbigh Grits is variable but low. Even in the ribbon-banded mudstones from the Coed Soflan section (CS/PS 1-9; basal Denbigh Grits) (average absolute abundance 0.1 palynomorphs/g, average species diversity 1.2) and the argillaceous sediments of the Llanddoget Formation (OER/PS 1-9) (average absolute abundance 0.15 palynomorphs/g, average species diversity 1.48) palynomorph abundance and species diversity is still very low.

A notable increase of both species diversity (4.8) and absolute abundance of palynomorphs (0.77/g) is in the lowest Lower Nantglyn Flags Group (BRA/PS 1); although with the incoming of carbonate and a shelly fauna in the Lower Mottled Mudstone, the absolute abundance and diversity of the palynomorphs is greatly reduced, in fact one sample (BRA/PS 3) is barren of palynomorphs.

3.10.e Biostratigraphy (see Fig. 34)

Poor preservation and low abundance and diversity of recovered palynomorphs from the Llanrwst section hampers a high resolution correlation with the Wenlock type area. The presence of Ordovician acritarchs in some samples (OER/PS 3,8) indicates that there is some reworking of older material. Correlation using the palynomorphs is therefore tentative, although suggested ages can be better supported in the basinal sections by the more common occurrence of zonal graptolites.

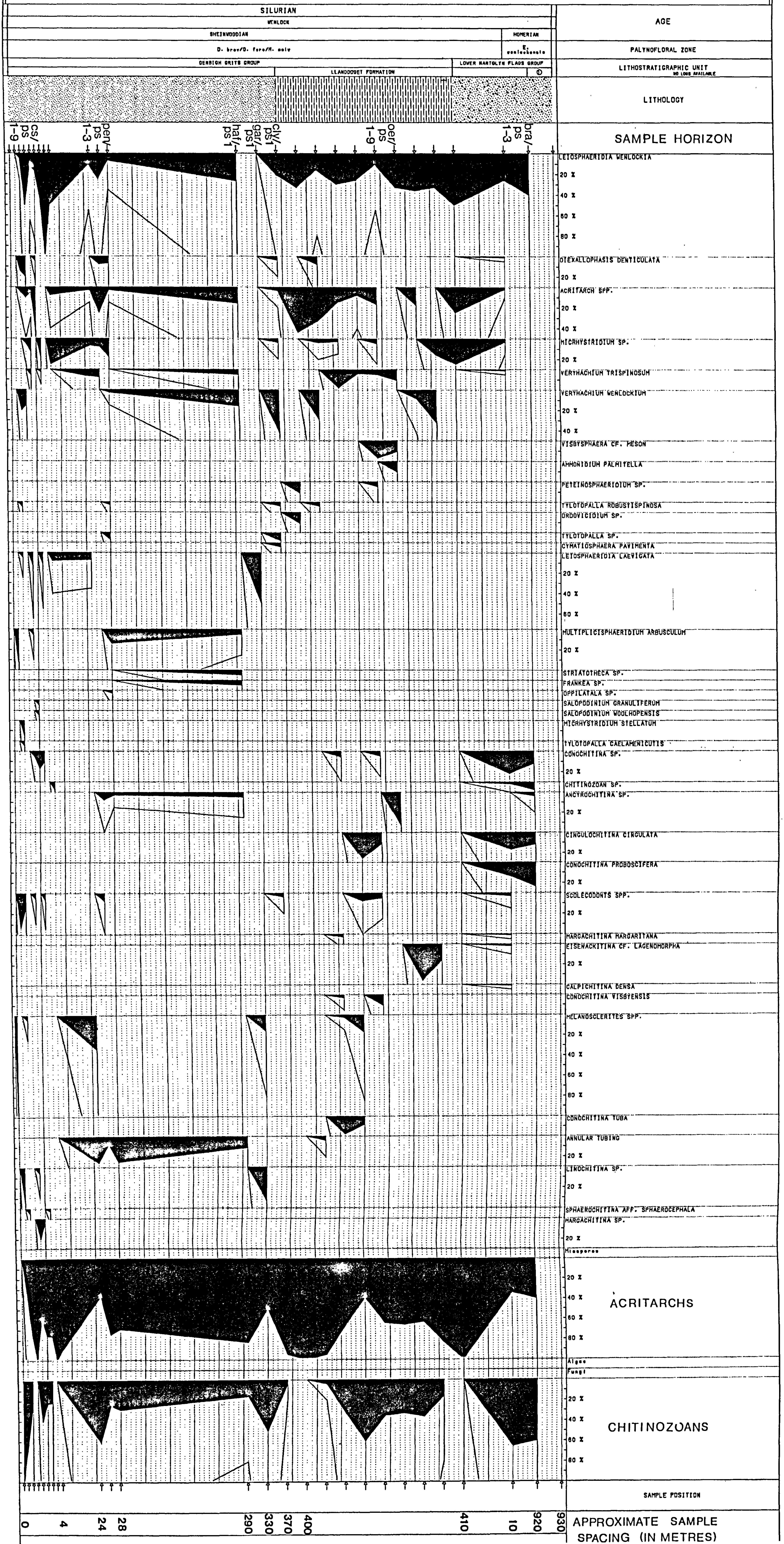
If the palynomorphs are not reworked then the presence of *Tylotopalla caelamenicutis* Loeblich 1969 in CS/PS 3 (sample 3), *Salopidium woolhopensis* Dorning 1981a in CS/PS 6 (sample 6) and *Cymatiosphaera pavimenta* (Deflandre 1945) Deflandre 1954 in CLY/PS 1 (sample 15) means that this lower part of the Denbigh Grits Group (samples 1-15) correlates to a depth of 165.00-166.52m (MPA 26066) (the highest occurrence of *Cymatiosphaera pavimenta* (Deflandre 1945) Deflandre 1954) and below in the Lower Hill Farm borehole in the Wenlock type area (lower Coalbrookdale and Buildwas formations). This agrees with the graptolite distribution in both sections which indicate a *rigidus* Biozone age and older (mid to early Sheinwoodian).

Presence of the acritarch *Ammonidium palmitella* (Cramer & Diez 1972a) Dorning 1981a in OER/PS 6 (sample 21) in the Llanddoget Formation

LLANRWST

FIGURE NO. 34

Normalized Palynological frequency diagram for the COMPOSITE SECTION OF LLANRWST, GWYNEDD



correlates to a depth of 101.04-102.57m (MPA 26054) or below in the Lower Hill Farm borehole, and is indicative of the *linnarssoni* Biozone or older (late to early Sheinwoodian). The first occurrence of the chitinozoan *Cingulochitina cingulata* (Eisenack 1937) is in sample OER/PS 4 (sample 19). Graptolites have not been recorded from the section at Oerfa quarry, but on regional evidence the Llanddoget Formation is recorded as being of *rigidus* to *linnarssoni* age (Warren *et al*. 1984).

The epibole in abundance of the chitinozoan taxon *Cingulochitina cingulata* (Eisenack 1937) and the highest occurrence of the chitinozoan *Margachitina margaritana* (Eisenack 1937) in a sample from the Lower Nantglyn Flags Group (BRA/PS 1; sample 25), correlates to a depth between 85.62-87.20m (MPA 26051) and 67.54-68.97m (MPA 26046) in the Lower Hill Farm borehole. This broadly agrees with the graptolite data as both this part of the Lower Nantglyn Flags Group (BRA/PS 1-3) and the corresponding section in the Lower Hill Farm borehole (76.73-78.28m to 63.51-64.69m (MPA 26049 to 26045)) have been dated on graptolite evidence as being of *ellesae* to *lundgreni* age (late Sheinwoodian to early Homerian).

3.11. The Conway composite section (see Fig. 35)

Samples 1-5. (BEN/PS 2,4,6,8,10). Conway Castle View estate (SH 7820 7722). Samples collected from the Benarth Flags, comprising ribbon banded silty mudstones and siltstones; the sampling interval is 4m. Graptolites were recovered from sample 2 and these have been identified (Dr D. White, British Geological Survey) as Monoclimacis vomerina, Monograptus riccartonensis and Monograptus priodon, indicative of the riccartonensis Biozone.

Samples 6-7. (CROE/PS 1,2). Croeseau (SH 8012 7340).
Exposure in two old quarries near Croseau farm, where in descending stratigraphical order the section is:-

Upper Quarry
6.0m Sandstones, medium to fine and coarse-grained; beds average 1 to 1.5m with convoluted and disturbed tops; mudstone flakes common; melange/disturbed bed of silty mudstone. Sample 7 (CROE/PS 2) is a silty mudstone.

Lower Quarry
0.6m Sandstone, fine-grained, with convoluted top
0-0.30m Silty mudstone; disturbed bed. Sample 6 (CROE/PS 1) collected.
2.7m fine to medium grained sandstone, alternating with silty mudstones
1.5m Mudstone, silty, dark grey: ? disturbed bed; coarse sandstone fills hollows in upper surface.

Sample 8. (LLYN/PS 1). Llyn Syberi (SH 7901 6982). Sample collected from the lake side where the lithology is a striped silty mudstone.

Samples 9-11. (BER/PS 1-3). Berllan Fawr (SH 8019 6985), type section for the Berllan Formation. Exposures in stream bed; three samples collected of dark grey, mostly laminated silty mudstone and siltstones.

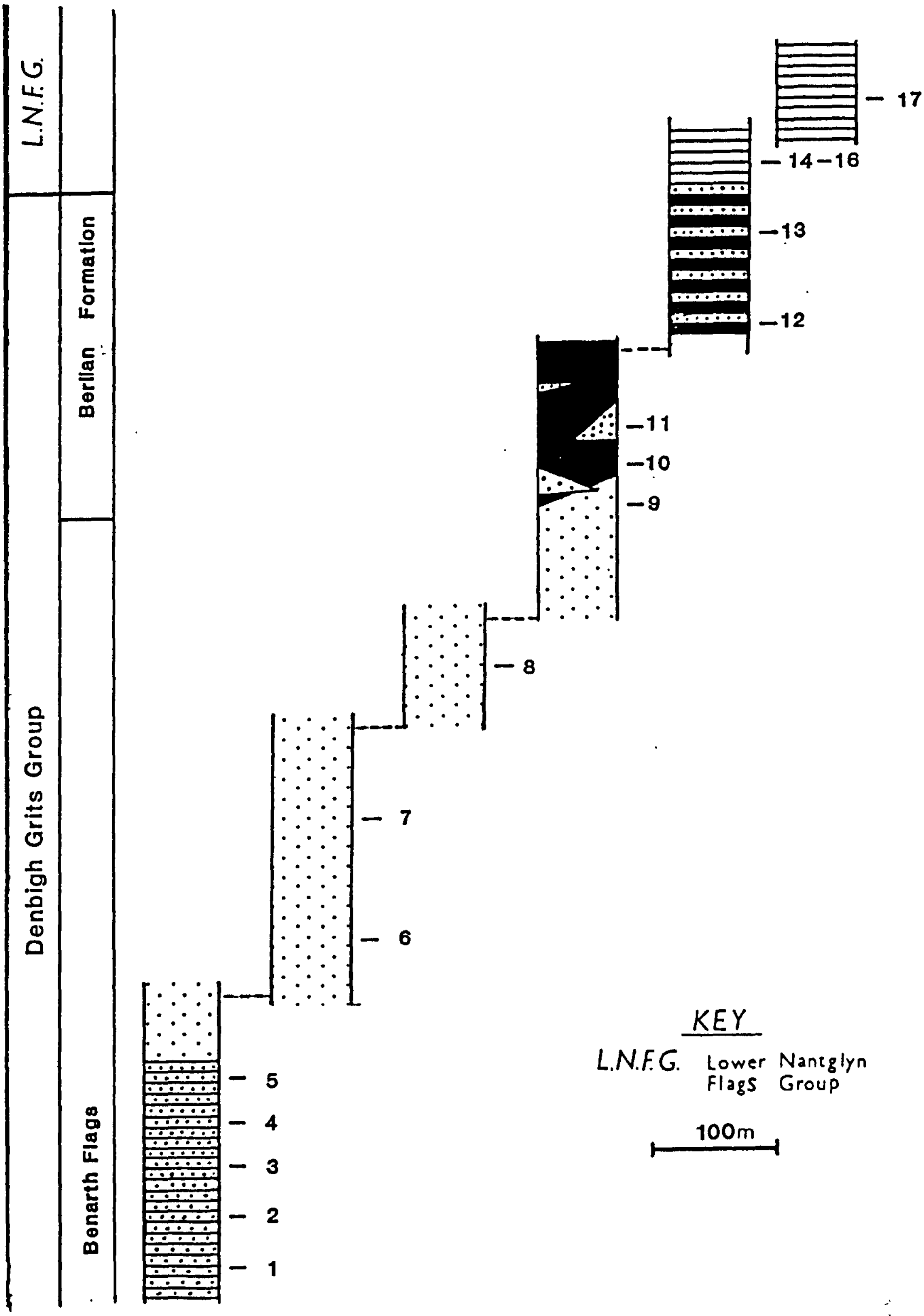


Fig. 35. Composite section in the Conway area, North Wales.

Sample 12. (TERR/PS 1). Terrace Wood (SH 8020 7279)
Sample collected from an old quarry in the wood. The lithology is of pencil slate (a disturbed bed) belonging to the Berllan Formation.

Sample 13. (BRYM/PS 1). Brymbo (SH 8046 7179)
Roadside exposure. Sample of fine silty mudstone belonging to the Berllan Formation. The exposure has previously yielded graptolites belonging to the *perneri* Biozone (=*linnarssoni* Biozone) (Warren *et al*. 1984, p.69).

Sample 14-16. (RHA/PS 1-3). Nant-Y-Rhaglaw (SH 8084 7046)
Samples collected from exposure near stream where public footpath crosses; the lithology is dark grey silty mudstone with some laminated muddy siltstone, belonging to the Lower Nantglyn Flags Group.

Sample 17. (FFR/PS 1). Frith-Arw (SH 8210 6587)
Roadside exposure. One sample collected of thinly bedded, ribbon banded silty mudstone belonging to the Lower Nantglyn Flags Group. Graptolites have previously been recovered here placing the exposure in the *lundgreni* Biozone (Homerian) (Warren et al. 1984, p.69).

3.11.a. Palynomorph preservation and distribution in the section

The recovered palynomorph assemblage is poorly preserved. Absolute abundance is low (range 0-0.89 palynomorphs/g; average 0.19 palynomorphs/g) as is species diversity (range 0-3.8; average 1.5). Palynomorph distribution is illustrated in Fig. 36

3.11.b. Acritarchs

Thermal maturation of the organic fraction is high and there are many black carbonised unidentifiable fragments of which some are undoubtedly acritarchs. Most of the identifiable acritarchs are damaged in some way. Absolute abundance (range 0-0.62 acritarchs/g; average 0.14 palynomorphs/g) is correspondingly low, with small thick-walled leiospheres (*Leiosphaeridia wenlockia* Downie 1959) being the predominant acritarchs (accounting for 81% of the acritarch assemblage); other acritarch groups are rare. The acritarchs are particularly sparse in the Benarth Flags, (the two basal samples were barren of acritarchs), distribution otherwise is fairly

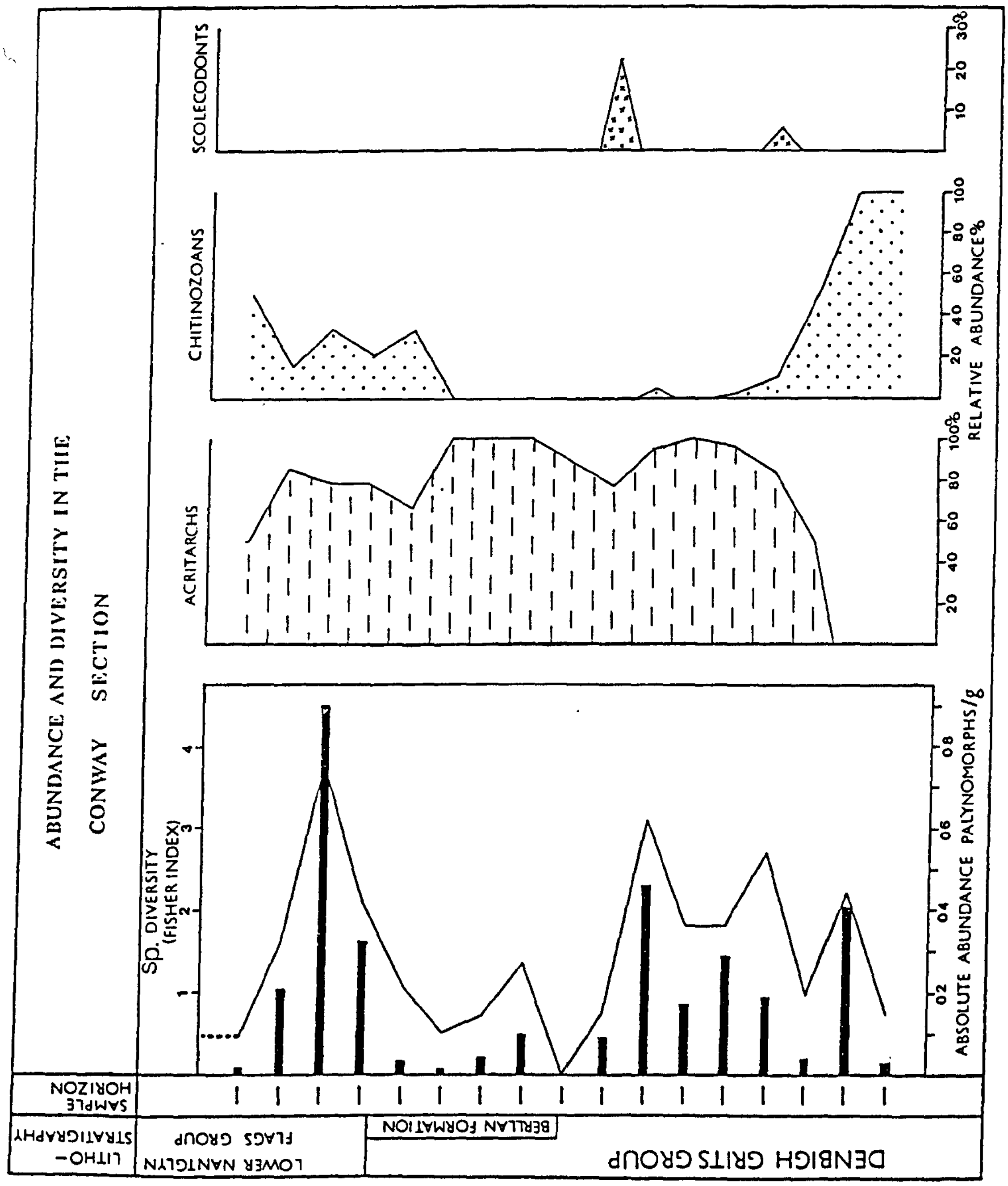


Fig. 36. Palynomorph absolute abundance and species diversity in the Conway section.

uniform. Unlike the Llanrwst section there are no recorded Ordovician acritarchs in any of the studied samples, although this does not discount reworking.

3.11.c. Chitinozoans and scolecodonts

The chitinozoans are typically of moderate to low abundance and diversity. They are present in all the studied samples from the Benarth Flags, being most numerous for the section in one of the samples (BEN/PS 4 (sample 2); absolute abundance 0.4 chitinozoans/g) that is barren of acritarchs. They are also relatively numerous in the silty mudstones of the Lower Nantglyn Flags Group (RHAN/PS 1-3 (samples 14-16); average absolute abundance 0.12 chitinozoans/g). Chitinozoans are absent or rare in the samples from the Berllan Formation and the 'main body' of the Denbigh Grits (average absolute abundance 0.002 chitinozoans/g); they were not recorded from six of the seven studied samples from this part of the section.

Scolecodonts were recovered but are not abundant at any level in the section. Organic debris in the form of Melanosclerites spp. and annular tubing was recovered but only in small amounts. Trilete spores were not recorded although fragments of questionable plant cuticle were noted at one horizon (LLYN/PS 1; sample 8).

3.11.d. Biostratigraphy (see Fig. 37)

There were no zonally useful acritarchs recovered from the Conway section; Tylotopalla robustispinosa (Downie 1959) Eisenack et al. 1973 present at a number of horizons is indicative only of a general Wenlock age.

Two chitinozoan taxa which can be correlated to the studied sections in the Wenlock type area (Lower Hill Farm borehole and Whitwell Coppice) are Cingulochitina cingulata (Eisenack 1937) which is present in sample RHA/PS 1 (sample 14) and Margachitina margaritana (Eisenack 1937) which is present in RHA/PS 2 (sample 15); the presence of the latter taxon in particular indicates that the section is no younger than mid-Wenlock (early Homerian) in age.

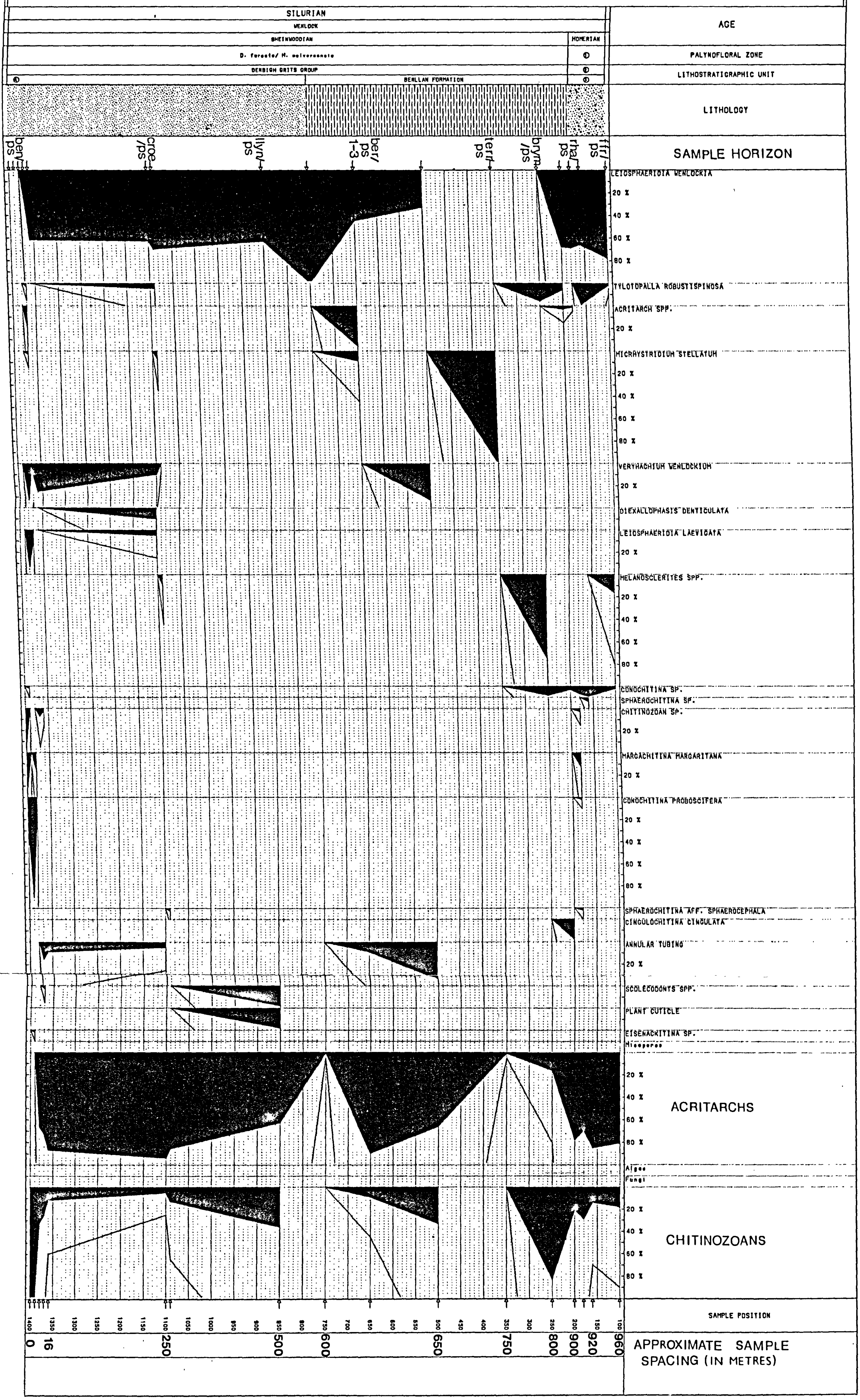
3.11.e. Comparisons and contrasts between the Llanrwst and Conway sections

Because of the very poor preservation of the palynomorph assemblages from both sections and the subsequent effect on both abundance and species

CONWAY SECTION

FIGURE NO. 37

Normalized Palynological frequency diagram for the COMPOSITE SECTION AT CONWAY SECTION, GWYNEDD



diversity, any comparisons of distribution have to be tentative ones. In the Denbigh Grits Group both species diversity and absolute abundance is quite variable as is the relative distribution of acritarchs, chitinozoans and scolecodonts. There is no obvious distributional pattern to characterise the Berllan Formation of the Conway area, nor the chronostratigraphically equivalent Llanddoget Formation of the Llanrwst area.

The average absolute abundance for the Denbigh Grits Group in the Conway area is 0.14 palynomorphs/g and the average species diversity 1.4. In the Llanrwst area the average absolute abundance is 0.13 palynomorphs/g and the average species diversity is 1.6; both sections are therefore quite comparable although deriving any palaeoenvironmental conclusions from such poorly preserved material has to be undertaken with caution.

One comaparable feature in both sections is the acme in both absolute abundance and species diversity in shales from the lowermost Lower Nantglyn Flags Group. In the Llanrwst section (BRA/PS 1; sample 25) the peak in abundance is 0.77 palynomorphs/g while species diversity is 4.8; in the Conway section (RHAN/PS 2; sample 15) the peak in abundance is 0.89 palynomorphs/g and species diversity is 3.8. There is a rapid decrease in both absolute abundance and species diversity stratigraphically above these samples; in the Llanrwst section the youngest sample (BRA/PS 3; sample 27) is from the more carbonate rich Lower Mottled Mudstone, this sample is barren of palynomorphs. The absolute abundance of the top sample from the Conway section (FRR/PS 1; sample 17) is only 0.01 palynomorphs/g and the species diversity is 0.45; this sample is from a shale just below the Lower Mottled Mudstone.

3.12. Conclusions for the basinal sections

Preservation of the palynomorphs is so poor in the collected sections that the relative proportions, absolute abundances and true diversity of the original assemblage are most likely not represented. Also there is evidence sedimentologically for strong turbiditic currents (graded bedding, prod marks, groove casts etc.), and synsedimentary slumping (see pencil slates p.46 and Warren *et al*. 1984, p.38) at different horizons in the collected sequences through the Denbigh Grits; both could be responsible for reworking, mixing and transport of palynomorphs.

The relative increase in numbers of chitinozoans in the basinal samples is probably partially due to the group being more robust and disintegrating at higher temperatures than the acritarchs (Jenkins 1970; Laufeld 1973). Counter to this is the fact that previously it has been noted from inshore to offshore shelf transects that chitinozoan abundance and species diversity do increase away from ancient inferred shorelines (see Laufeld 1974, p. 121), and they are commonly recovered in sediments from deeper basins (Verniers 1982); this possibly indicates, that chitinozoans existed if not preferentially then 'quite happily' in deeper water environments.

A relative increase in numbers of small thick-walled leiospheres in the basinal samples is more likely to be a representation of the original assemblage, as they can be compared directly in proportion to the other recovered acritarchs (that is presuming they are no more robust than the other represented groups). This dominance of thick-walled leiospheres in deep water assemblages has previously been noted by Dorning (1981c, p.33).

In conclusion, although it is possible to hypothesize about the original deep water palynomorph assemblages of the Welsh basin, these ideas must be tested with assemblages elsewhere that are better preserved, and that are less disturbed.

CHAPTER 4

A BIOZONATION FOR THE EARLY WENLOCK

4.1. Previous acritarch biozonational schemes

A first attempt at a biozonation for the early Wenlock of the type area was by Hill (1974b) who established two assemblage zones 5 and 5a, using species of the acritarch taxa *Domasia* Downie 1960 and *Deunffia* Downie 1960 to define the zones. These two zones approximate to the W1 range zone of Dorning (1981a) which he defined on the recorded stratigraphical ranges of the acritarchs *Dateriocradus algerensis* (Cramer & Diez 1972a) Dorning 1981a, *Deunffia brevispinosa* Downie 1960 and *Deunffia furcata* Downie 1960. The W2 biozone of Dorning (1981a) corresponds to his recorded range of *Cymatiosphaera pavimenta* (Deflandre 1945) Deflandre 1954 and the acme of *Tylotopalla wenlockia* Dorning 1981a. The W3 biozone of Dorning (1981a) corresponds to the stratigraphical ranges of the acritarchs *Eisenackidium wenlockensis* Dorning 1981a, *Estiastra granulata* Downie 1963 and *Multiplicisphaeridium wrensnestensis* Dorning 1981a. The stratigraphical ranges of species which he used to establish this biozonal scheme are illustrated in Dorning (1981a pp.177-180).

The acritarch zones have since been correlated to the standard chrono- and lithostratigraphy in the Wenlock type area (Dorning & Bell 1987) and tentatively to the graptolite biozones (Hill & Dorning 1984; Bassett 1989, fig. 49), with zone W1 (and 5a) equivalent to the *centrifugus* Biozone, W2 equivalent to the *murchisoni* to *lundgreni* biozones and W3 equivalent to the *nassa* and *ludensis* biozones.

Most recently Dorning & Hill ('1991' in press) established a new, higher resolution zonal scheme, which is defined on the consecutive first occurrences of different 'distinctive acritarch species' (partial-range biozones), each first occurrence defining the base of a new biozone. The acritarch biozones were renamed after the species used by Dorning & Hill ('1991' in press) to define them 'in order to avoid confusion as a result of the same specific epithet being used twice'. The early Wenlock biozones were named after the acritarch species Deunffia brevispinosa Downie 1960, Deunffia brevifurcata Hill 1974b, Cymatiosphaera pavimenta (Deflandre 1945) Deflandre 1954 and Eisenackidium wenlockensis Dorning 1981a, the four biozones replacing the previous three zones (W1 to W3) of Dorning (1981a).

4.1.a A revised acritarch zonation

The biostratigraphical results from the Wenlock type area (Lower Hill Farm borehole and Whitwell Coppice section) and supportive data from the Eastnor Park borehole in the Malverns can be used for testing and here revising the established biozonational schemes (see Dorning 1981a; Dorning & Bell 1987, p.268, fig. 15.2 and Bassett 1989, p.71, fig. 49; and Dorning & Hill '1991' in press). The Lower Hill Farm borehole is extremely useful because of its cored nature (through most of the Coalbrookdale Formation and all of the Buildwas Formation), its position in the Wenlock type area and because of the recognition of zonal graptolites in the section (Bassett et al. 1975, fig.3). The Whitwell Coppice section is of use because it is the international stratotype for the Sheinwoodian/ Homerian stage boundary of the Wenlock (again defined on graptolite data; see Bassett et al. 1975, p.14). The Eastnor Park borehole is of use because of its cored nature (including the whole of the Woolhope Limestone), but in particular because the palynomorph assemblages in the borehole are abundant, well preserved and diverse.

Although in the other studied sections preservation is generally poor and/or palynomorph abundance and diversity is low, some of the data can also be used in supporting the revised biozonational scheme.

A higher resolution partial-range zonal scheme, based on first occurrences, is not attainable because, although during the mid and late Sheinwoodian there were a number of species extinctions (highest occurrences), there were very few first occurrences of taxa. In addition the ranges of some of these taxa in the studied sections do not have a uniform consecutive pattern and especially in the late Sheinwoodian are overlapping, indicating possibly some facies control on ranges, or even some small scale reworking of palynomorphs.

Taking these factors into consideration, proposed below are four acritarch total-range biozones. Three of the biozones (the Deunffia brevispinosa, Deunffia furcata (ex Deunffia brevifurcata) and Eisenackidium wenlockensis biozones) have previously been defined using the same species that are used in this study (Dorning & Bell 1987), although the boundaries for these biozones have been moved to accomodate new range data. One range biozone, the Helosphaeridium malvernensis Biozone, is here proposed for the first time and replaces the Cymatiosphaera pavimenta Biozone of Dorning & Bell 1987; this is because the range of Cymatiosphaera pavimenta in this study is extended down into what is probably the latest Llandovery (Telychian) (see the Eastnor Park borehole p.26-34). The acritarch zonation is complimented by two proposed chitinozoan total-range biozones. The new proposed biozones are illustrated in Fig. 38, where they are compared to other biozonational schemes.

The well documented occurrence of the acritarchs and the chitinozoans, defining the range biozones in sections not only within the Welsh Basin, but also in other sections from northern Europe and North America means that they may be used not only for local but also for international correlation (see occurrences in Systematic Palaeontology section, Chapter 7).

(1) The Deunffia brevispinosa Total-Range Biozone

The biozone is based on the stratigraphical range of Deunffia brevispinosa Downie 1960; Deunffia ramusculosa Downie 1960 has a similar stratigraphical range. Both acritarchs occur in the Lower Hill Farm borehole at the base of the Buildwas Formation in sample MPA 26084 at a depth of 239.14-239.66m; this correlates to the lowermost part of the centrifugus Biozone. Mabillard & Aldridge 1985 record the first occurrences of both Deunffia brevispinosa Downie 1960 and Deunffia ramusculosa Downie 1960 from the uppermost Purple Shales (latest Llandovery) of the Leasows section in the Wenlock type area.

(2) The Deunffia furcata Total-Range Biozone

The biozone is based on the stratigraphical range of Deunffia furcata Downie 1960; in the Lower Hill Farm borehole this is from sample MPA 26083 at a depth of 234.57-236.07m to sample MPA 26076 at a depth of 203.12-204.65m. The acritarch species Fractoricoronula checkleyensis (Dorning 1981a) emend. and Alveosphaera ? deflandrei (Stockmans & Willière 1963) Priewalder 1987, have their first occurrences in this interval (both in

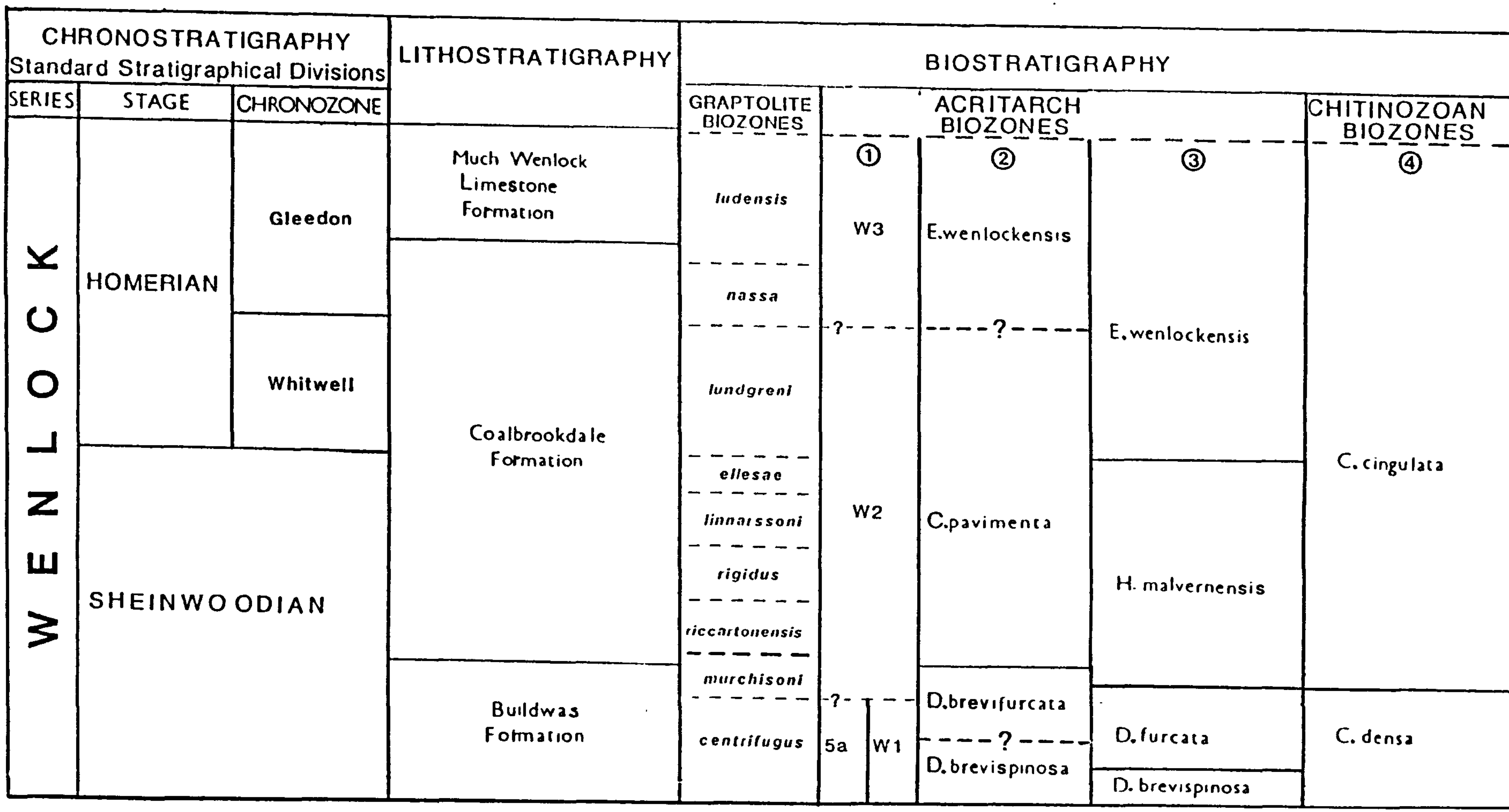


Fig. 38. A biozonation for the early Wenlock. Acritarch biozonation: 1. zone 5a is a zone of Hill & Dorning (1984), zones W1 to W3 are from Dorning (1981a). 2. After Dorning & Bell 1987 and Dorning & Hill '1991' (in press). 3. a new proposed acritarch biozonation. 4. a new proposed chitinozoan biozonation.

sample MPA 26083 in the Lower Hill Farm borehole at a depth of 234.57-236.07m).

The highest occurrence of Deunffia furcata Downie 1960 in the Lower Hill Farm borehole (203.12-204.65m) correlates approximately to the top of the centrifugus graptolite biozone (Bassett et al. 1975, p.5, fig.3). As it is proposed in this study that Deunffia brevifurcata Hill 1974b is synonymous to Deunffia furcata Downie 1960 (see systematic descriptions p. 259) the Deunffia brevifurcata Biozone of Dorning & Bell (1987) here becomes the Deunffia furcata Biozone.

(3) The Helosphaeridium malvernensis Total-Range Biozone

The biozone is based on the stratigraphical range of Helosphaeridium malvernensis Dorning 1981a. In the Lower Hill Farm borehole this is from sample MPA 26067 at a depth of 170.79-172.26m to sample MPA 26049 at a depth of 76.73-78.28m. Although the stratigraphical ranges of Deunffia furcata Downie 1960 and Helosphaeridium malvernensis Dorning 1981a are not recorded as being consecutive in the Lower Hill Farm borehole (there is a 30m interval from the the top of the range of Deunffia furcata to the base of the range of Helosphaeridium malvernensis), there is only a 4m difference in their ranges (one sample) in the Eastnor Park borehole (see Fig. 16); also Dorning 1981a records their ranges as being consecutive in other sections from the Wenlock type area.

Within this interval in the Lower Hill Farm borehole are a number of associated taxa; Fractoricoronula checkleyensis (Dorning 1981a) emend. has its highest occurrence in sample MPA 26062 at 144.98-146.45m, Salopidium woolhopensis Dorning 1981a has its highest occurrence in sample MPA 26060 at 134.57-136.04m and Tylotopalla caelamenicutis Loeblich 1970 has its highest occurrence in sample MPA 26056 at 111.68-113.36m.

The highest occurrence of Helosphaeridium malvernensis in the Whitwell Coppice section is in sample WC/PS 10.

The Helosphaeridum malvernensis Range Biozone correlates approximately to the riccartonensis, rigidus, linnarssoni and ellesae graptolite biozones (see Bassett et al. 1975, p.5, fig.3).

(5) The Eisenackidium wenlockensis Total-Range Biozone

The base of this zone is defined by the first occurrence of Eisenackidium wenlockensis Dorning 1981a. In the Lower Hill Farm borehole this is in sample MPA 26047 at 72.21-73.71m. In the Whitwell Coppice section this is in sample WC/PS 13.

The base of the Eisenackidium wenlockensis Biozone is within the lundgreni Graptolite Biozone (see Bassett et al. 1975, p.5, fig.3). Dorning 1981a records the highest occurrence of Eisenackidium wenlockensis from the upper Wenlock Limestone of the Wenlock type area.

4.2. Previous chitinozoan biozonational schemes

In spite of the large biostratigraphical potential for almost all chitinozoan species, no standard biozonation is yet available for the group, even though some authors (e.g. Taugourdeau & De Jekhowsky 1960; Magloire 1967, Cramer & Diez 1978; Paris 1981; Verniers 1982) have attempted to erect local or regional biozonations. One reason is the paucity of published data on the type areas for the Silurian.

4.2.a. A proposed chitinozoan biozonation

In support of the acritarch biozones two chitinozoan total-range biozones can be established for the Wenlock of the type area, these can be observed in a majority of the studied sections and are therefore of use in a regional correlation of Wales and the Welsh Borderland. Because of the widespread occurrences of the taxa, for instance in other sections from northern Europe, North America and in sections from North Africa (see occurrences in Systematic Palaeontology section, Chapter 7), and because they are here defined in the Wenlock type area, they may also be of use in international correlation.

(1) The Calpichitina (Densichitina) densa Total-Range Biozone

The zone is based on the stratigraphical range of Calpichitina (Densichitina) densa (Eisenack 1962a). The first occurrence of this taxon is in the latest Llandovery Purple Shales of the Wenlock type area (see Dorning 1981b), its highest occurrence in the Lower Hill Farm borehole is in sample MPA 26076 at a depth of 203.12-204.65m (near the top of the Buildwas Formation). The recorded stratigraphical range of the chitinozoan

Salopochitina bella Swire 1990 in the Lower Hill Farm borehole is within this biozone.

(2) The Cingulochitina cingulata Total-Range Biozone

The base of this zone is defined on the first occurrence of Cingulochitina cingulata (Eisenack 1937), this is in sample MPA 26073 at a depth of 198.48-199.14m in the Lower Hill Farm borehole, at the base of the Coalbrookdale Formation. The highest occurrence of Cingulochitina cingulata (Eisenack 1937) is recorded as being in the Wenlock Limestone (Dorning 1981b) ,this defines the top of the biozone in the Wenlock type area.

Although their is an interval of some 3m between the top occurrence of Calpichitina (Densichitina) densa (Eisenack 1962a) and the first occurrence of Cingulochitina cingulata (Eisenack 1937) in the Lower Hill Farm borehole, Paris (1989) indicates that there ranges in a number of Silurian sections in northern Europe are consecutive.

CHAPTER 5

THERMAL MATURATION

5.1. Introduction

At increased temperatures all fossil organic material undergoes thermal alteration. Temperature ranges for alteration varies due to the variety in composition of the original organic materials (Dorning 1986). Most organic materials show a colour change through dark brown to black and both increased translucency and reflectance; different organic materials exhibit a different colour, transparency and reflectance at any given palaeotemperature (Dorning 1986). Optical changes are due to slow carbonization and particularly to the loss of molecular hydrogen and oxygen from the complex organic compounds (Cooper 1977). The palynomorph groups studied exhibit varying changes when exposed to higher temperatures; these changes are summarised below.

5.1.a. Acritarchs

Thermally unaltered acritarchs are colourless to pale yellow, they show colour changes through dark browns to grey or black, this depending on wall thickness (Cooper 1977, Dorning 1987). Forms with a thin, single, smooth wall, such as *Micrhystridium* Deflandre 1937 emend. Staplin 1961, *Veryhachium* Deunff ex Downie 1959 and *Leiosphaeridia* Eisenack 1958a are more suitable for palaeotemperature analysis. Forms with more than one wall can show differences in colouration between the inner and outer walls (Dorning 1986). Legall *et al*. (1981) using selected species of *Leiosphaeridia*, proposed acritarch alteration indices (AAI) on a scale of 1-5, these were calibrated with conodont colour alteration indices. Dorning (1986) stated that acanthomorph acritarchs show much the same progressive colour changes at significantly higher temperatureS than the sphaeromorphs studied by Legall *et al*. (1981).

5.1.b. Chitinozoans and scolecodonts

At low palaeotemperatures, chitinozoa and scolecodonts are light to dark brown in colour. The chitinozoan wall and individual scolecodont elements are of a very variable thickness, for meaningful comparative results measurements must be made on the same selected part of the fossil (Dorning 1986). At higher palaeotemperatures, the colour changes to black or sometimes grey. It is possible to use chitinozoa as an alternative to vitrinite for reflectance studies, in samples where vitrinite is not present (Goodarzi 1985).

5.1.c. Spores and plant fragments

Plant tissue suitable for vitrinite reflectance studies is recorded from the mid-Silurian to recent. The original colour of land plant material is often pale yellow to brown and shows progressive changes through dark browns to black (Dorning 1986). Gutjahr (1966) studied pollen and spore translucency and related them to hydrocarbon thermal maturation; he noted increased translucency of the exines at higher temperatures. Staplin (1969) showed palynomorph colours as a thermal alteration index (TAI), this has been widely used as a scale in visual estimation of pollen and spore colouration.

5.1.d. Graptolite fragments

Optical changes in fragments of graptolites are poorly documented (Heroux et al. 1979, Goodarzi 1984), although generally they show changes in colour from various shades of brown to black with increasing palaeotemperatures; the changes are similar to those of chitinozoans and scolecodonts.

Calibration of the results from optical analyses to exact palaeotemperatures is complicated by potential variables including sediment lithology, rock pH, humic staining and oxidation (Dorning 1986). Taking these variables into account though, palaeotemperatures may be derived from fossil organic material for temperatures in the range of 50-450°C. Analyses for palaeotemperatures from organic fossils may be carried out with standard palynological preparations (see Staplin 1982, p.7), that is if no oxidation is used during processing (which is generally the case in this study). Oxidation lightens the colour of organic materials, with most change in organic material of low thermal alteration (Dorning 1986, p.220).

Palaeotemperature values in different tectonic provinces are associated with variations in the overburden thickness, rock conductivity and heat flow. Overburden can be produced by later sediments in a subsiding basin; or it may be produced by thrust faulting of rock over the sediments, introducing a great thickness of overburden. Other tectonic activity such as larger scale plate subduction or smaller scale faulting and folding may also generate higher temperatures. High thermal alteration values in restricted areas can often be related to local high heat flow associated with igneous intrusions, or even to hydrothermal activity.

5.2. Results

For standardisation of results as suggested by Legall et al. 1981 the single acritarch genus Leiosphaeridia Eisenack 1958a, was chosen for study primarily because of the relatively large size (22-80μ) of the specimens, the relative structural simplicity and by the fact that Leiosphaeridia is very common and occurs in all the studied sections. Two species of Leiosphaeridia were used L. laevigata Stockmans & Willière 1963 and L. wenlockia Downie 1959. Legall et al. (1981, p. 509) noted that size and wall thickness determines the extent of colouration of the leiospheres, with thin-walled species being consistently lighter in colour than thicker-walled species in the same thermal alteration zone. Although this is probable, in the present study it would appear that the colour differences created by different wall thicknesses are slight and no obviously visible differences are seen in the same zone between the thinner-walled L. laevigata Stockmans & Willière 1963 and the thicker-walled L. wenlockia Downie 1959. This is illustrated in plate 37 where for instance the colour alteration of specimens of both species of Leiosphaeridia from the Brinkmarsh Formation indicate an alteration index of 3.

Leiospheres proved to be excellent in calibrating the shelf sections where thermal maturity is very low to moderate, but in the basinal sections of central eastern Wales and North Wales, the thermal maturity of the leiospheres is above the limit (90°C) at which they show any further progressive colour changes. Dorning (1986, p. 219) noted that progressive colour changes in acanthomorphic acritarchs have been recorded at higher palaeotemperatures than those for the leiospheres. Three acanthomorphs recovered from the basinal sections are illustrated in plate 38; these do not show any visible differences in colour (black) from the leiospheres, indicating (that is if Dorning's statement is correct) temperatures much higher than 90°C. Temperatures are restricted to below 450-460°C as palynomorphs are destroyed in this range (Barnard et al. 1981).

For consistency all illustrated specimens were photographed using a Leitz Labrolux microscope and an Olympus OM10 camera; all the photographs were printed on Kodak paper.

5.2.a. The shelf sections

In the studied shelf sections of Tortworth, the Eastnor Park borehole, the Lower Hill Farm borehole, Whitwell Coppice and Dolyhir the Acritarch Alteration Index (AAI) varies between 2 and 4 (see Plate 37). The most immature sections are the Lower Hill Farm borehole, Whitwell Coppice and Dolyhir; observed leiospheres have an AAI of 2 and display incipient maturation (see Legall et al. 1981, fig. 9). The leiospheres in these sections are light to pale yellow in colour indicating burial temperatures of 60°-70°C. Leiospheres from the Tortworth section have an AAI of 3 and are pale yellow to orange in colour indicating maturity and a burial temperature of 70°-80°C (Legall et al. 1981, fig. 9). The leiospheres from the Eastnor Park borehole display the greatest maturity of all the shelf sections with an AAI of 4 (the leiospheres from this section are orange to dark brown in colour), this is indicative of burial temperatures of 80°-90°C.

In the Tortworth area the colour of the Wenlock rocks is typically grey or yellowish grey, but the once overlying Keuper Marl is responsible for the strata in many parts of the area having been stained pink, red or purple; this previous overburden combined with synclinal folding and faulting and also possibly residual heat flow from Llandovery volcanic activity in the area have all possibly contributed to the higher thermal maturity of the palynomorphs.

Thermal maturation of conodonts recovered from the Eastnor Park borehole (Aldridge pers. comm.) and from elsewhere in the Malverns (Aldridge 1986) indicate a maximum thermal regime in the region of 60-140°C, dependent on duration of heating (Epstein et al. 1977). The conodont colour alteration index (CAI of Epstein et al. 1977) has a general value of 2-2.5, this correlates with the determined acritarch colour alteration index of 4 (Legall et al. 1981). As there is no evidence of Ordovician or post Ordovician igneous activity, the temperatures were probably raised to this level by burial under a now-removed overburden, presumably mainly of marine Silurian and fluviatile Old Red Sandstone sediments.

The low thermal maturity of the palynomorphs recorded in the Lower Hill Farm borehole and the Whitwell Coppice section suggests that in the Wenlock type area there was previously very little overburden. Apart from the occurrence of irregular bentonite horizons in the Coalbrookdale Formation there is little evidence for volcanic activity in the area. The presence of only minor faulting in the Wenlock type area has also limited the possible tectonic influence on thermal maturity.

The low thermal maturity of the palynomorphs in the Dolyhir section suggests that there was previously little overburden in the area. There is also no geological evidence for any local volcanic activity. There has, been some tectonic influence, with the Church Stretton lineament (which is represented by a number of faults transecting both the Dolyhir Limestone and overlying Coalbrookdale Formation) passing through the area, although the faulting seems to have had little effect on palynomorph thermal maturity.

5.2.b. Offshore shelf and basin

The leiospheres from the Pistyll Quarry section, the Llanrwst section and the Conway section are all black in colour (see plate 38) and are comparable with AAI 5 of Legall et al. (1981) which is calibrated with temperatures of between 90°C and 185°C. Earlier work by Staplin (1969) and Kantsler et al. 1978 on dispersed particulate organic matter suggests that the colour change from brown to black (i.e. to the colour of the leiospheres from these sections) takes place at approximately 170°C-200°C. The indication is that the palaeotemperature attained in the three sections lies within the range 90°C-460°C (the temperature at which palynomorphs are destroyed), and probably towards the higher end of that range.

The high palaeotemperatures attained by the Nant-ysgollon Shales of Pistyll Quarry, and the Denbigh Grits and Lower Nantglyn Flags of the Llanwrst and Conway sections are probably due to a number of factors including a previously thick overburden of Carboniferous and possibly Permo-Triassic sediments. Also faulting is common, (especially in the

Denbigh Grits) and this too may have had some influence on thermal maturity. It is also possible that after all the volcanic activity during the Ordovician in North Wales, that cooling might have been slow and the residual high heat flow may have affected the thermal maturity of later deposited Silurian sediments.

CHAPTER 6

PALAEOECOLOGY

6.1. Introduction

In contrast to other palynomorph groups and other microfossil groups the acritarchs and chitinozoans have received little attention as far as palaeoecological interpretation is concerned. Previously several authors have suggested some facies control over the distribution of the acritarchs (e.g. Staplin 1961; Combaz 1968; Smith & Saunders 1970; Martin 1974). Gray & Boucot (1972) proposed a depth stratification model, while Riegel (1974) differentiated what he considered a neritic assemblage from a *Leiosphaeridia* Eisenack 1958a dominated assemblage found in a more restricted environment. Jacobsen (1977b) considered *Leiosphaeridia* a shallow water form. Vall (1965) described acritarch assemblages from the early Jurassic of England and concluded that small spinose acanthomorph acritarchs (mainly *Micrhystridium* spp.) are characteristic of inshore environments, with the short spined species being concentrated in high energy environments and the longer spined species being typical of low energy environments. Cramer and Diez published a series of papers (summarized in Cramer & Diez 1974a) on the paleobiogeography of Silurian microplankton which are difficult to interpret. Vavrdova (1974) has suggested that two provinces can be distinguished in Ordovician microfloras of Europe. Jacobsen (1979) and Dorning (1981a, 1987) considered the regional distribution patterns of the acritarchs to be affected by water depth and nutrient supply, while Colbath (1980) interpreted the differences to be the result of water mass fluctuations. Dorning (1987) and Dorning & Bell (1987) discussed acritarch and chitinozoan distribution in the Much Wenlock Limestone Formation of Shropshire, naming four assemblages and associating them with particular palaeoenvironments.

Very few papers, if any, have attempted to deal solely with the palaeoecology of the chitinozoans, normally comments are made secondarily to biostratigraphical aspects of the group. Laufeld (1974) noted that abundance of chitinozoans is inversely proportional to the amount of calcium carbonate present in the rocks. He also noted a preponderance of a species of Sphaerochitina Eisenack 1955a in shallow water sediments. Grahn (1981) noted that chitinozoans were planktic, pseudoplanktic or mobile enough to be more or less easily dispersed by water movements to environments quite different from the biotope of the 'chitinozoophoran'. In addition, factors such as general or unusual current conditions, temperature and salinity must have played an important role in the distribution of the chitinozoans. Al-Ameri (1983), dealing with palynomorphs (complete organic residues) as palaeoenvironmental indicators in the Palaeozoic of Libya, suggested six distinct types of palynofacies which he tentatively related to lagoonal, intermediate and open marine environments. Although he suggested that chitinozoans increase in diversity offshore, he associated some morphologically complex forms with a lagoonal facies.

It is probable that the main reason for the lack of publications on the palaeoecology of both the acritarchs and chitinozoans is the unknown biological affinities of the groups. Certain assumptions, however, can be made and in the results discussed below it is assumed that the acritarchs are in the main microphytoplankton; exceptions are the leiospheres which are thought to be algal spores and also some of the herkomorphs and pteromorphs which are thought to be prasinophycean algae (see Downie 1973, Dorning 1987). It is also assumed that the chitinozoans are the egg-cases of annelid worms (see Dorning 1987, p.261) of which the scolecodonts are the jaw apparatuses, this certainly seems to be the case for at least some of the chitinozoans, for instance robust and large conochitinids in some of the samples from North Wales are associated with large and robust scolecodonts. The idea that chitinozoans are egg-cases is supported by the occurrence of chitinozoan chains and cocoons, the general morphology of the chitinozoan vesicle and the lack of observed ontogeny in the group.

6.2. The distribution of the different palynomorph groups across the early Wenlock shelf and basin

The total organic residue recovered from the studied samples can be separated into five palynomorph groups: 1. acritarchs 2. chitinozoans 3. scolecodonts 4. organic debris (including cuticle, Melanosclerites spp., and annular tubing) and 5. trilete spores.

In general the acritarchs, chitinozoans and scolecodonts are restricted to marine environments with their distribution probably related to a number of factors including depth, light, temperature, salinity, current flow energy, turbulence, oxygen availability and also, for some of the chitinozoans and scolecodonts, types of substrate. The acritarchs are believed to be exclusively planktic in habit, although because of the diverse nature of this polyphyletic group there is a certain amount of facies control affecting the different acritarch taxa (for instance thin-walled leiospheres, ? algal spores are more abundant in shallow water environments).

If the chitinozoans are presumed to have been planktic this would have aided distribution and would help to explain their generally ubiquitous nature. The presence of complex ornament and appendices on some taxa may have aided as floating devices (see Chaiffetz 1972). Scolecodonts were undoubtedly benthic, as they are jaws of annelid worms that lived and burrowed in soft muddy substrates (Dorning 1987). It is perhaps reasonable to assume that the possible relationship of scolecodonts to conochitinid chitinozoans suggests that these chitinozoans were benthic. The absence of ornament or appendices (? floating devices) on these chitinozoan taxa would be consistent. Also the absence of chains may indicate that dispersal was primarily due to the parent animal in conochitinid chitinozoans; chains perhaps, are only associated with planktic, current dispersed taxa.

The relative abundances of the different palynomorph groups for each studied section is illustrated in Fig. 39. The diagram shows that across the shelf and basin the acritarchs are the dominant group accounting for as much as 96% of the organic fraction at Dolyhir (they average over 90% of the organic fraction in the shelf sediments down to 51.14% of the organic fraction in the Llanrwst section). Chitinozoans, in contrast, are rare in the Tortworth and Dolyhir sections accounting for only 0.3 and 2% of the assemblage respectively; they account for a consistent 5 to 5.5% of the assemblage over the rest of the shelf and shelf margin and increase relatively in abundance in the basinal turbiditic samples of the Conway and Llanrwst sections (averaging 28% of the organic fraction). The relative increase of chitinozoans in the basinal sediments is possibly partly related to the high thermal maturity of the organic fraction and differential destruction of the acritarchs and other palynomorphs;

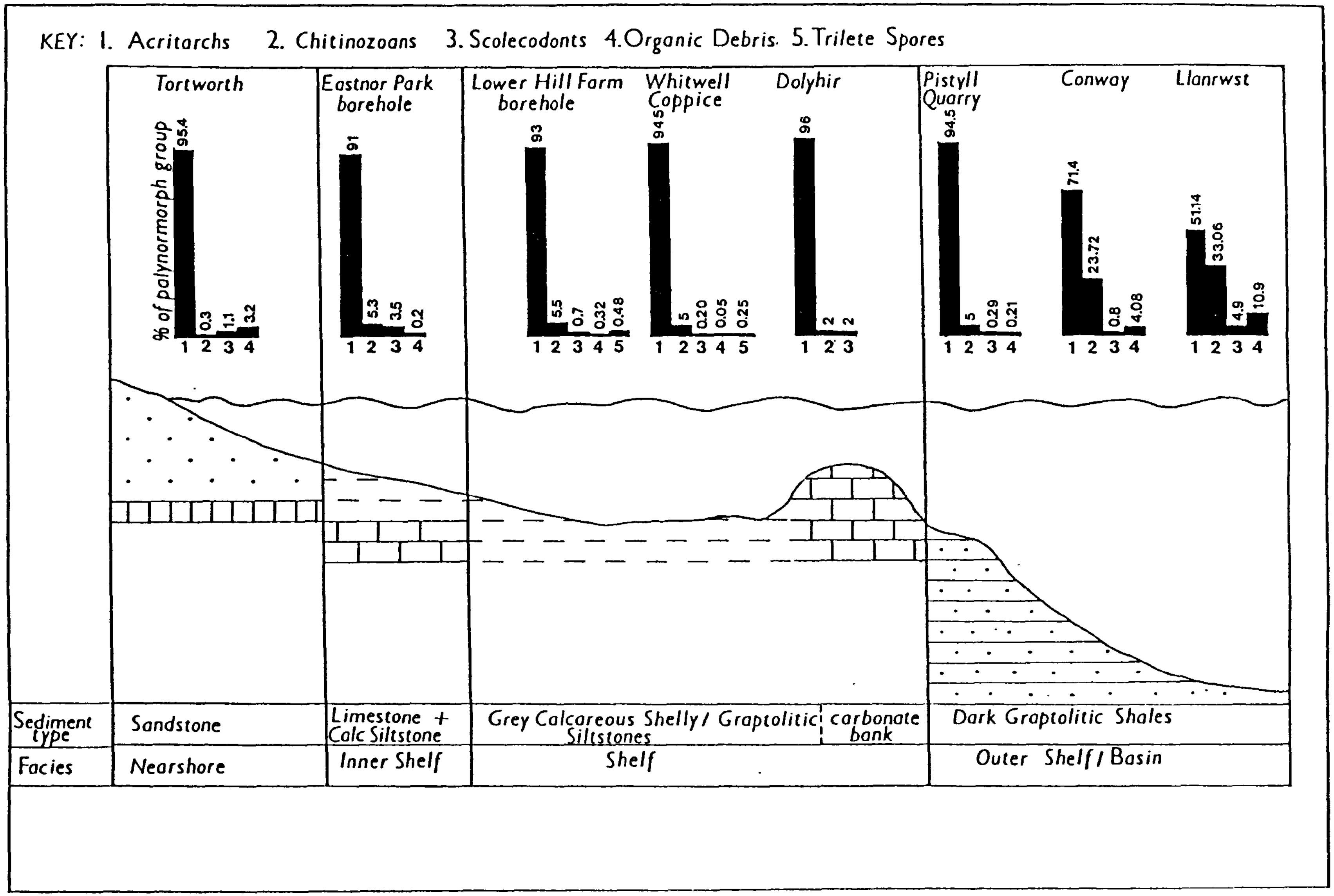


Fig. 39. A diagrammatic representation showing proportions of the different palynomorph groups in a section and how they vary across the early Wenlock shelf and basin of Wales and the Welsh Borderlands.

chitinozoans are more robust and are destroyed at much higher temperatures (Jenkins 1970). Chitinozoans were however consistently recovered from the basinal sediments and in some samples are quite numerous, also exclusive taxa such as Sphaerochitina aff. sphaerocephala (Eisenack 1932) were recovered, indicating some environmental preference.

Scolecodonts are never abundant in the studied sections although they occur in all. At their highest relative abundance, in the Llanrwst section scolecodonts account for 4.9% of the assemblage, at their lowest relative abundance in the Whitwell Coppice section they account for only 0.05% of the assemblage. Apart from the apparent association of large conochitinid chitinozoans and scolecodonts in some of the basinal samples a more tenous link can be observed in the Eastnor Park borehole where abundances of Conochitina proboscifera Eisenack 1937 can possibly be linked with correspondingly high abundances of scolecodonts; these scolecodonts are smaller and thinner-walled than the more robust basinal ones. The link is more tenous because the chitinozoan assemblage here is more abundant and diverse than in the basinal samples and therefore there is more 'background noise'. The link could possibly extended to the shelf sections of the Lower Hill Farm borehole and Whitwell Coppice, although this is even harder to demonstrate as the chitinozoans are even more abundant and diverse.

Organic debris in the form of Melanosclerites spp., annular tubing , plant cuticle and graptolite prosiculae are not particularly abundant in any one section, although they do occur consistently in each section apart from Dolyhir. Relative abundance is highest in the Llanrwst section (4.9%) where Melanosclerites spp. and annular tubes are quite common. There is also a notable abundance of Melanosclerites spp. in a sample from the Buildwas Formation of the Lower Hill Farm borehole (MPA 26083).

Trilete spores are the rarest of all the palynomorph groups. They were not recovered from the palaeoenvironmentally nearer-shore sections of either Tortworth or the Eastnor Park borehole; in the only two sections from which they were recovered (the Lower Hill Farm borehole and Whitwell Coppice) they constitute only a minor part of the assemblage (0.48 and 0.25% respectively). The occurrence of trilete spores in two of the shelf sequences and their abscence from the Tortworth and Malvern sections indicates a derivation from another direction. Trilete spores have previously been recovered in abundance from the early Wenlock of the Usk area (Lister & Downie 1969, p.204). A derivation of the spores from the Usk area would fit the north-eastwards current direction proposed by Bassett (1974, p.771). Even though this direction was deduced for the turbiditic sediments of the Welsh basin, a gentler but similar directional current could have flowed along the shelf basin margin as far east as the Much Venlock area.

6.3. Relative abundances of the different acritarch groups

How relative abundances of the acritarch groups vary in each studied section is illustrated in Fig. 40. The groups are divided into 1. the sphaeromorphs 2. the herkomorphs and pteromorphs 3. the polygonomorphs and netromorphs and 4. the acanthomorphs. The dominant acritarch group in the nearshore section of Tortworth, the shallow-water carbonate-bank of Dolyhir and the three outer shelf/basinal sections (Pistyll Quarry, the Conway and Llanrwst sections) is the sphaeromorphs; in these sections they account for 56.17 to 85% of the assemblage. In the shelf sections of the Eastnor Park borehole, the Lower Hill Farm borehole and the Whitwell Coppice section the sphaeromorphs are relatively less abundant accounting for 23.73 to 25.51% of the assemblage.

The acanthomorphs are the second most abundant acritarch group; in contrast to the sphaeromorphs they are relatively least abundant in the Tortworth section, the Dolyhir section and the three outer shelf/basinal sections, accounting for 12.49 to 30.64% of the assemblage. They are dominant over the shelf accounting for as much as 62.26% of the assemblage in the Eastnor Park borehole down to 42.32% of the assemblage in the Whitwell Coppice section.

The herkomorph and pteromorph acritarchs are never abundant in the studied sections. They are very rare in the outer shelf/basinal samples and were not recorded from two of the sections (Pistyll Quarry and Conway). The greatest recorded abundance of this group was in the Whitwell Coppice section where they account for 5.07% of the assemblage; relative to the other sections they are also abundant in the Eastnor Park and Lower Hill farm boreholes (accounting for 3.81% and 1.94% of the assemblages respectively).

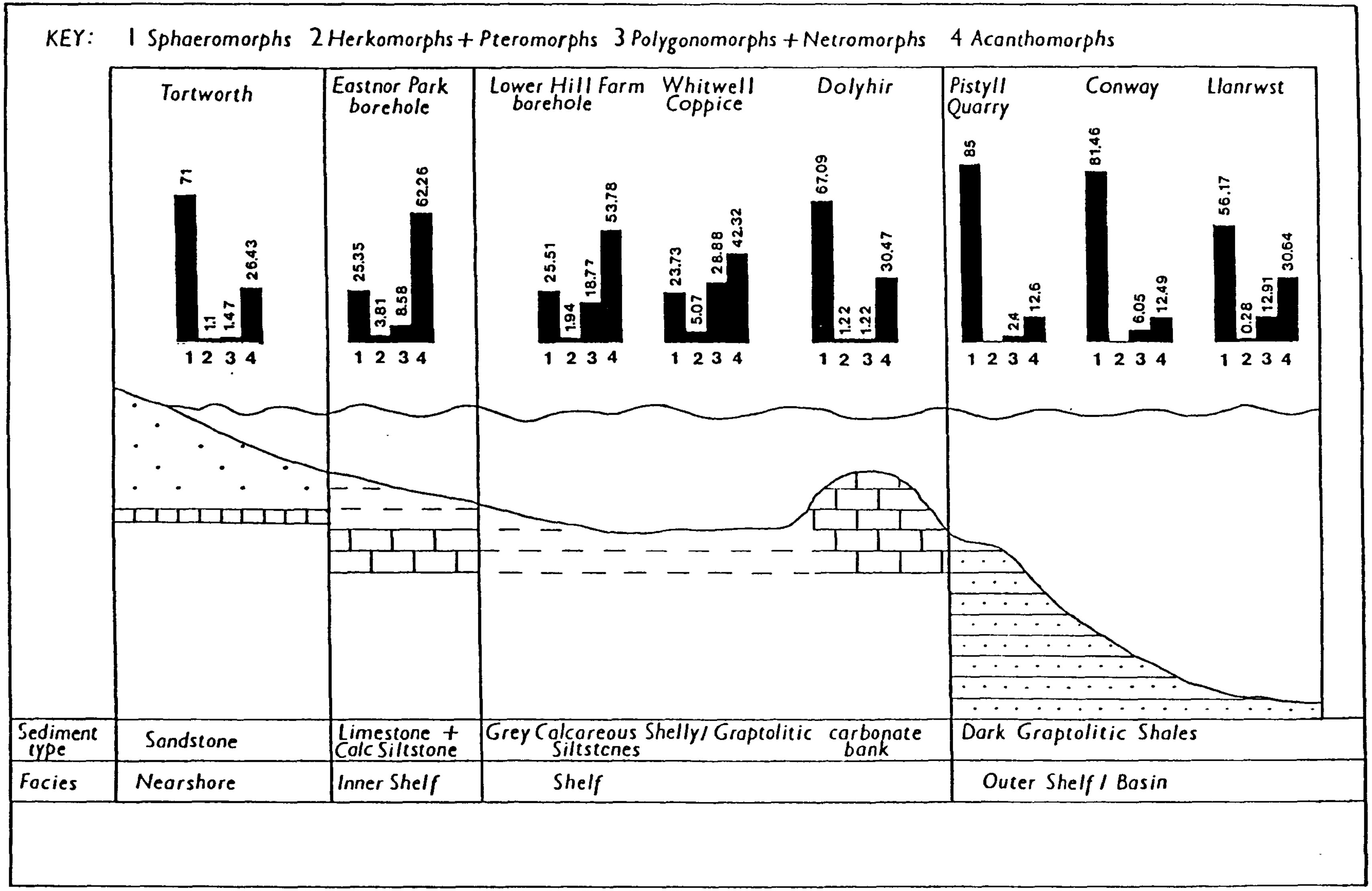


Fig. 40. A diagrammatic representation showing proportions of the different acritarch groups in a section and how they vary across the early Wenlock shelf and basin of Wales and the Welsh Borderlands.

The polygonomorph and netromorph acritarch are present in every studied section; the groups account for as little as 1.47% of the assemblage in the Tortworth section to as much as 28.88% of the assemblage in the Whitwell Coppice section, the latter due to an acme in abundance of Veryhachium wenlockium formgroup (Downie 1959) Downie & Sarjeant 1964 in the mid-Coalbrookdale Formation (in sample WC/PS 11), a feature also seen in the Lower Hill Farm borehole (from about 75 to 85m). In the Llanrwst section the polygonomorphs and netromorphs account for 12.91% of the palynomorphs, due to the relatively high abundance of Veryhachium wenlockium formgroup (Downie 1959) Downie & Sarjeant 1964 and Veryhachium trispinosum formgroup (Eisenack 1938) Deunff 1954 ex Downie 1959.

6.4. Relative abundances of the different chitinozoan groups

The chitinozoans in Fig. 41. have been split into the main genera, or generic pairs when there is a close morphological similarity such as between Angochitina Eisenack 1931 emend. 1968 and Gotlandochitina Laufeld 1974.

Conochitina Eisenack 1931 is the dominant genus of nearshore and basinal environments. At Tortworth it accounts for all of the chitinozoan assemblage (although abundance here is very low), while in both the Conway and Llanrwst sections it accounts for over 50% of the assemblage. At Dolyhir Conochitina constitutes 39.9% of the assemblage with relative abundances being affected by the presence of the 'offshore/shelf taxa' shelf taxa Cingulochitina Paris 1981 and Linochitina Eisenack 1968. Conochitina is also present in the other sections; in the Eastnor Park borehole it is the dominant genus along with Ancyrochitina Eisenack 1955a, which together account for 89.63% of the chitinozoan assemblage. Ancyrochitina is the dominant genus in the Lower Hill Farm borehole accounting for 42.99% of the chitinozoan assemblage; in the Whitwell Coppice section it accounts for only 1.3% of the assemblage. It is also present in the Dolyhir section and in the Llanrwst section, accounting for 13.33% and 6.3% of the chitinozoan assemblage respectively.

The Lower Hill Farm borehole and the Whitwell Coppice sections are affected by a flood of the species Cingulochitina cingulata (Eisenack 1937), which is particularly abundant in the mid-Coalbrookdale Formation.

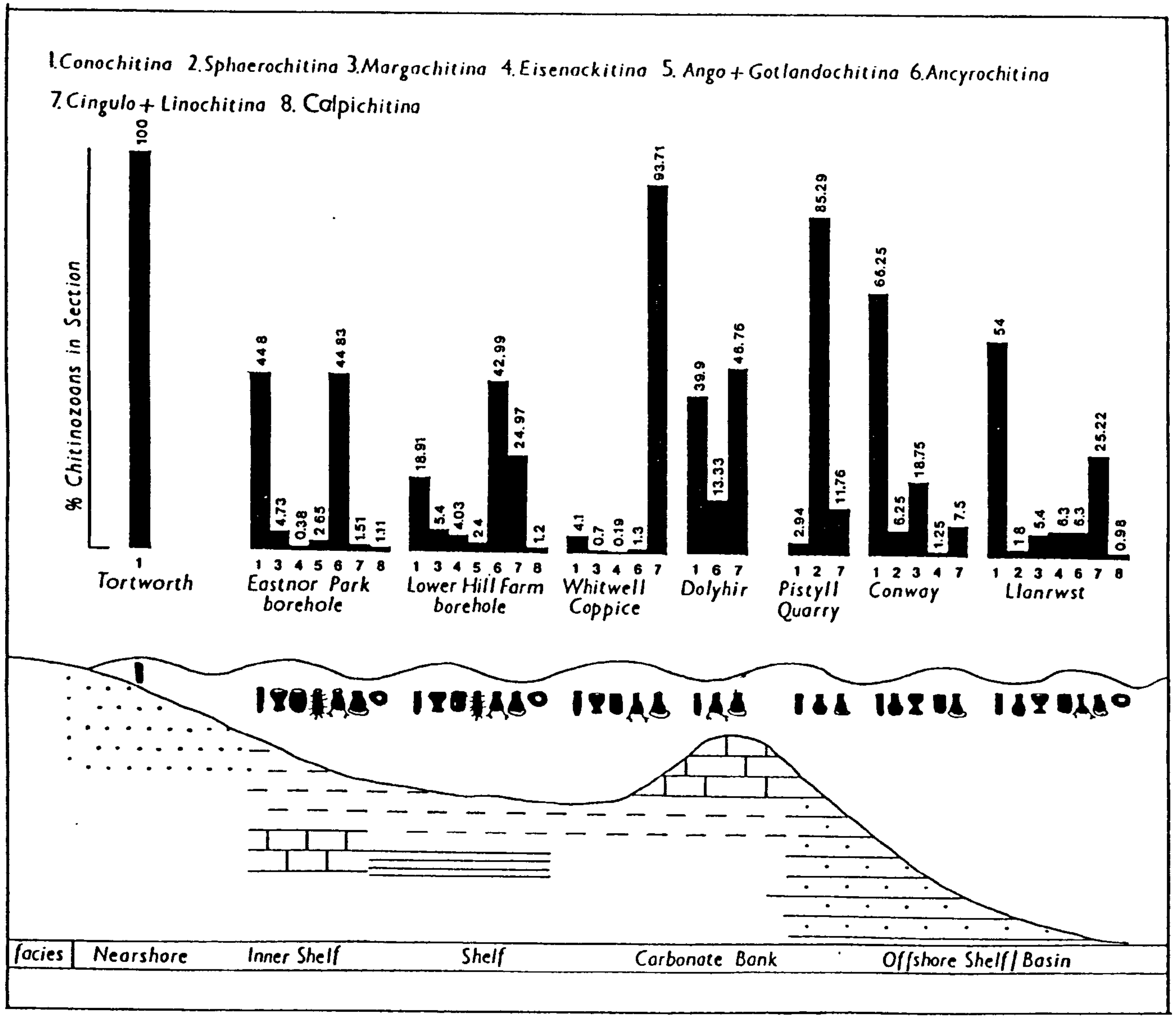


Fig. 41. A diagrammatic representation showing proportions of the different chitinozoan genera and how they vary across the early Wenlock shelf and basin of Wales and the Welsh Borderlands.

Cingulochitina and the closely related genus *Linochitina* account for 93.71% of the chitinozoan assemblage at Whitwell Coppice. In the stratigraphically longer section at Lower Hill Farm, *Cingulochitina* and *Linochitina* still account for 24.97% of the chitinozoan assemblage. There is a marked drop in relative abundance in the Eastnor Park section with the two genera accounting for only 1.51% of the assemblage. *Cingulochitina* and *Linochitina* are not exclusively shelf taxa, they occur in all three offshore/shelf and basinal sections accounting for as much as 25.22% of the chitinozoan assemblage in the Llanrwst section down to 7.5% of the assemblage in the Conway section.

Sphaerochitina Eisenack 1955a was not recovered from any of the nearshore shelf, or carbonate bank sediments and is extremely rare in the main shelf sediments. It is present in all three offshore/shelf and basinal sections; in the Pistyll quarry section *Sphaerochitina* is the dominant genus accounting for 85.29% of the chitinozoan assemblage, it is present to a lesser extent in the Conway and Llanrwst sections accounting for 6.25% and 1.8% of the chitinozoan assemblages respectively.

Two other genera *Margachitina* Eisenack 1968 and *Eisenackitina* Jansonius 1964 are present in shelf, offshore/shelf and basinal sediments. *Margachitina* accounts for 5.4% of the chitinozoan assemblage in the Lower Hill Farm borehole and 0.7% of the assemblage in the Whitwell Coppice section. It was not recovered from the shallow water sediments of Tortworth or Dolyhir, or from the Pistyll quarry section. *Margachitina* accounts for 18.75% of the assemblage in the Conway section and 5.4% of the assemblage in the Llanrwst section.

In the shelf sediments *Eisenackitina* accounts for as much as 4.03% of the assemblage in the Lower Hill Farm section to as little as 0.19% of the assemblage in the Whitwell Coppice section. It is not present in either the Tortworth or Dolyhir sections, but is present in both the Conway and Llanrwst sections accounting for 1.25% and 6.3% of the chitinozoan assemblages respectively.

The genera *Angochitina* Eisenack 1931 emend. 1968 and *Gotlandochitina* Laufeld 1974 were only recovered from the shelf sediments of the Eastnor Park and Lower Hill Farm boreholes, accounting for 2.65% and 2.4% of the chitinozoan assemblages respectively.

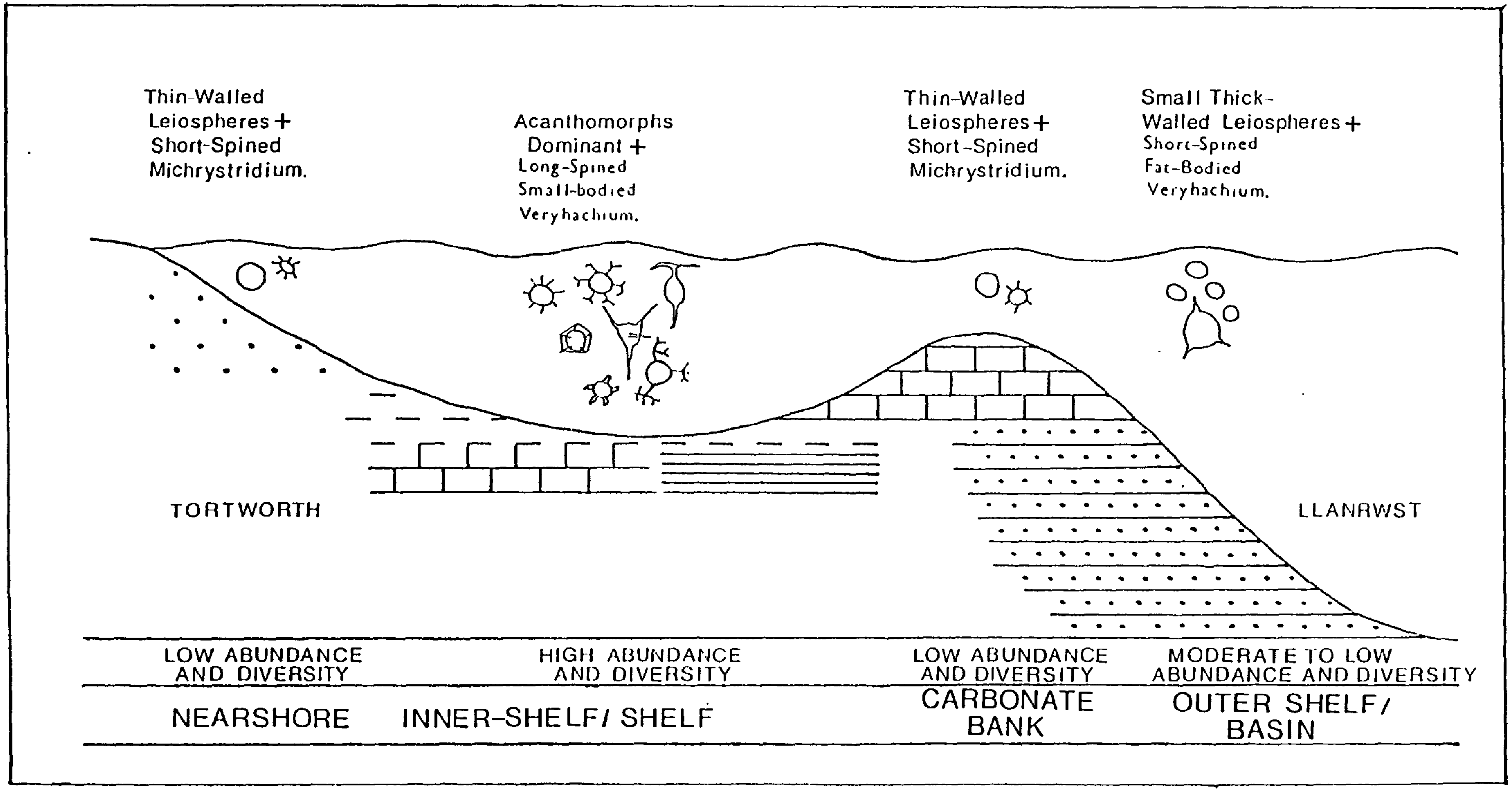


Fig. 42. Generalised distribution of acritarchs in the early Wenlock shelf and basin of Wales and the Welsh Borderlands.

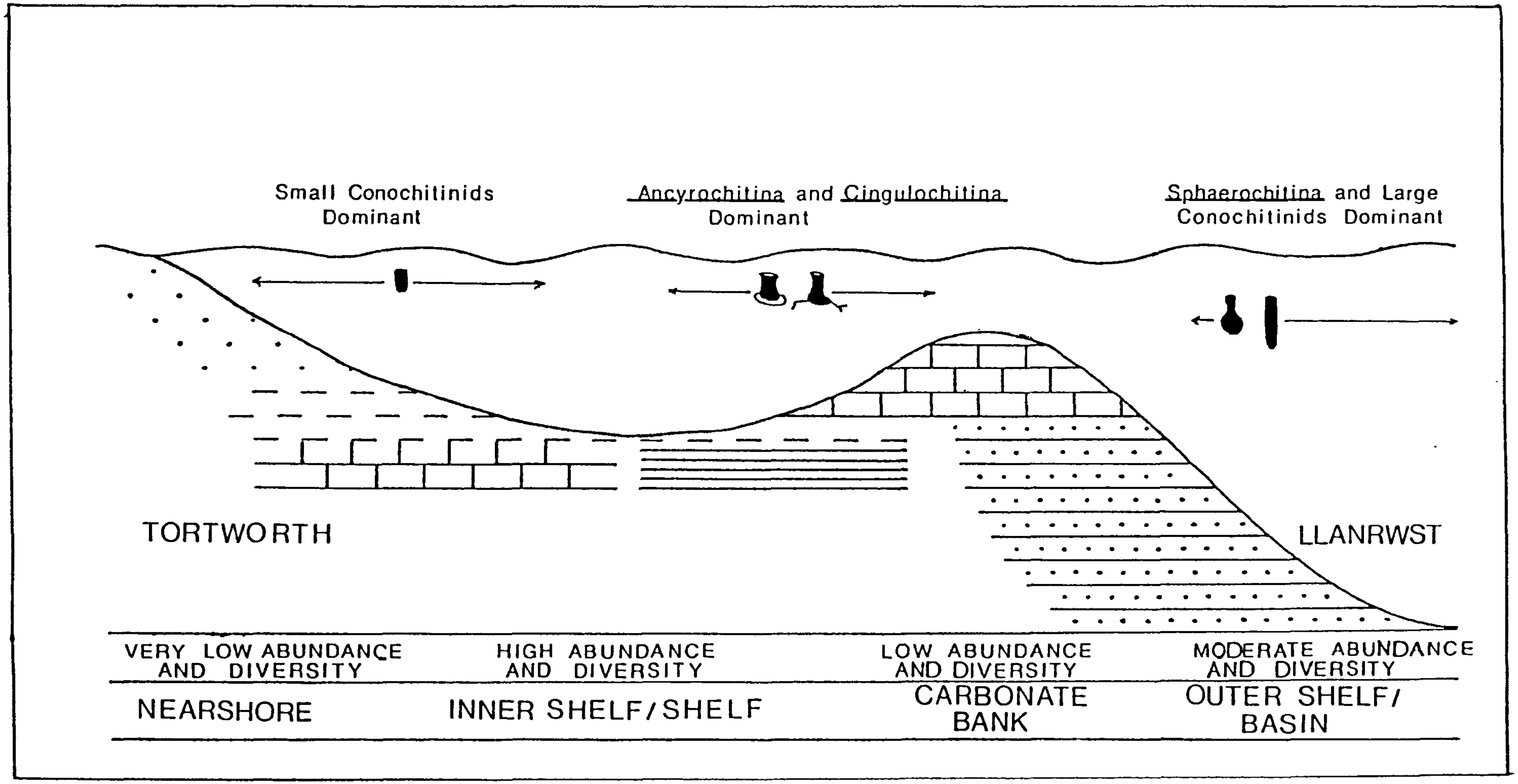


Fig. 43. Generalised distribution of chitinozoans in the early Wenlock shelf and basin of Wales and the Welsh Borderlands.

The genus Calpichitina Paris 1981 was also recovered in relatively small numbers from the shelf sediments, accounting for 1.21% of the chitinozoan assemblage in the Eastnor Park borehole and 1.2% in the Lower Hill Farm borehole. Calpichitina was also recovered from the basinal samples of the Llanrwst section accounting for 0.98% of the assemblage.

6.5. Discussion of palynomorph distribution

A generalised distribution pattern for the studied shelf to basin transect of the early Venlock of Wales and the Velsh Borderlands is illustrated in two figures; Fig. 42 shows a generalized distribution pattern for the acritarchs and Fig. 43 shows a generalized distribution pattern for the chitinozoans. As the diagrams illustrate, in the nearshore environment of the Tortworth area, there is a preponderance of thin-walled leiospheres and short-spined Michrystridium spp. Deflandre 1937 emend. Staplin 1961; chitinozoans are very rare here with only small conochitinids being represented. Acanthomorphic acritarchs dominate on the shelf, these tending to have longer processes than the nearshore and outer shelf/basinal forms; for instance specimens of Veryhachium Deunff ex Downie 1959 recovered from the shelf sediments mainly have small bodies and long processes compared with the fat-bodied forms with short processes that are more common in the basinal sediments.

The dominant chitinozoan genera of the shelf are the ancyrochitinids and cingulochitinids. The yield from the lithologies of Dolyhir is very similar to that of Tortworth with thin-walled leiospheres and short-spined Michrystridium spp. predominant. Offshore shelf and basinal lithologies are dominated by small thick-walled leiospheres, the most abundant chitinozoan genera are large robust conochitinids and sphaerochitinids.

Scolecodonts recovered from shelf sediments tend to be relatively small and thin-walled, while those from offshore shelf and basinal samples tend to be larger more robust forms.

6.6. Average species diversity and absolute abundances

Fig. 44 illustrates average species diversity and absolute abundance for the shelf-basin transect. In comparative terms the shallow water

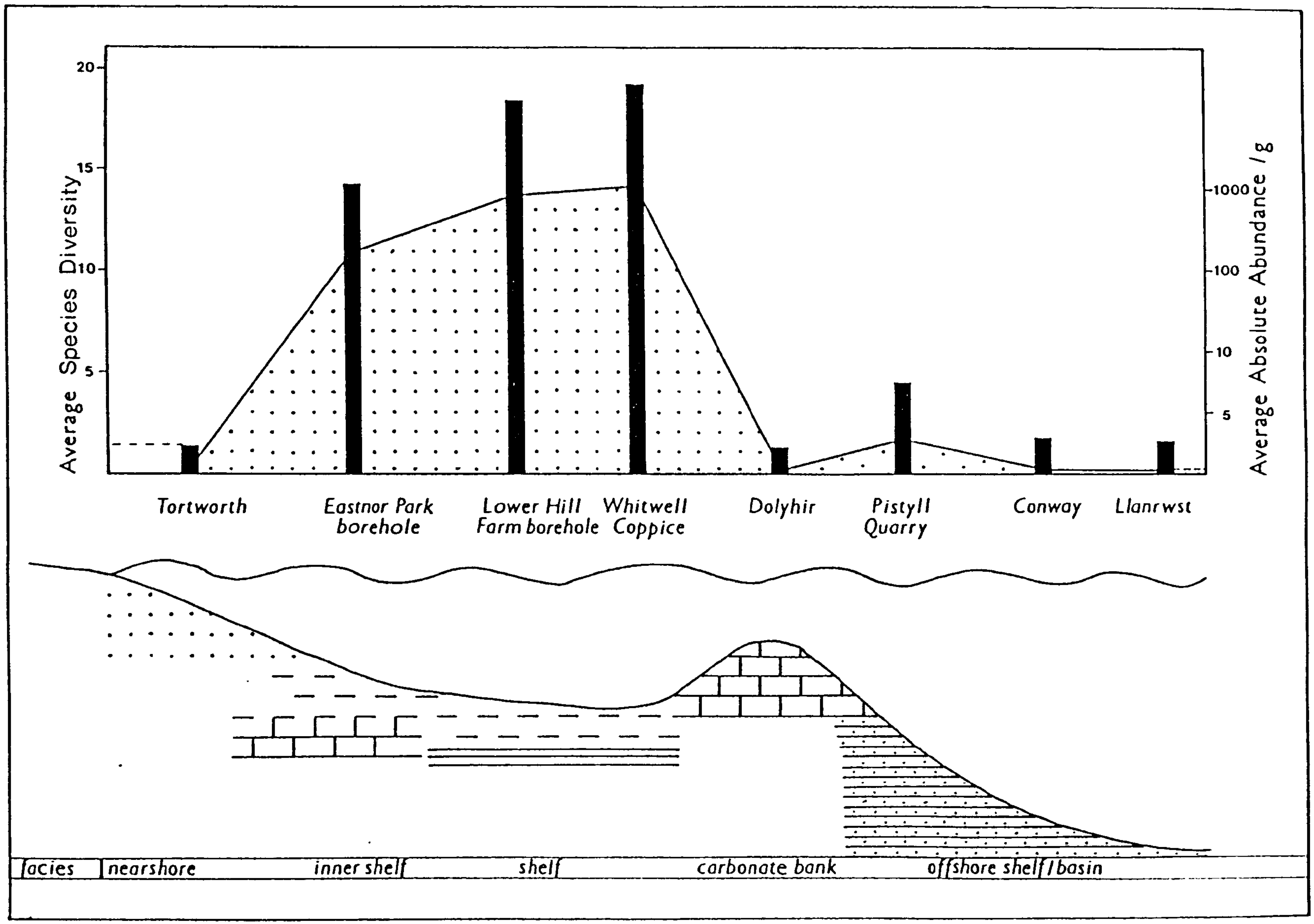


Fig. 44. Average species diversity and absolute abundance of palynomorphs in sections studied.

environments represented by Tortworth and Dolyhir have very low species diversity and absolute abundances, average species diversity is 1.15 and average absolute abundance 0.07 palynomorphs/g. Both absolute abundance and species diversity is also low in the offshore shelf and basinal sections (average species diversity 1.60, average absolute abundance 0.18 palynomorphs/g), with only a small rise in both in the Pistyll Quarry section where average species diversity is 7.45 and average absolute abundance is 2.78 palynomorphs/g.

The highest average species diversity and absolute abundances were recorded from the three inner shelf and shelf sections. Whitwell Coppice has the greatest yield, average species diversity is 19.3 and average absolute abundance is 1051/g; average species diversity (18.5) and average absolute abundance (963 palynomorphs/g) is comparable but slightly lower in the Lower Hill Farm borehole. Average species diversity (14.3) and average absolute abundance (306 palynomorphs/g) are appreciably lower in the Eastnor park borehole than in the Whitwell Coppice section and Lower Hill Farm borehole, but relative to the remaining sections both are still high.

Fig. 45 illustrates five cumulative frequency diagrams of average absolute abundances for the acritarchs, chitinozoans, scolecodonts, spores and organic debris in the eight studied sections. The graphs illustrate that the three shelf sections of the Eastnor Park and Lower Hill Farm boreholes and Whitwell Coppice section accounts for 99.85% of recovered acritarchs and 99.75% of recovered chitinozoans.

The shallow water sediments of Tortworth and Dolyhir account for 0.022% of recovered chitinozoans and 0.051% of recovered acritarchs. The offshore shelf and basinal sections of Pistyll Quarry, the Llanwrst section and the Conway section account for 0.13% of recovered acritarchs and 0.214% of the recovered chitinozoans.

Scolecodonts are most abundant in the shelf sections of Whitwell Coppice and the Eastnor Park and Lower Hill Farm boreholes where they account for 99.37% of those recovered. The Tortworth and Dolyhir sections account for 0.039%, while the three offshore shelf and basinal sections account for 0.059% of total recovered scolecodonts.

Trilete spores were only recovered from the three shelf sections of the Eastnor Park borehole, the Lower Hill Farm borehole and the Whitwell

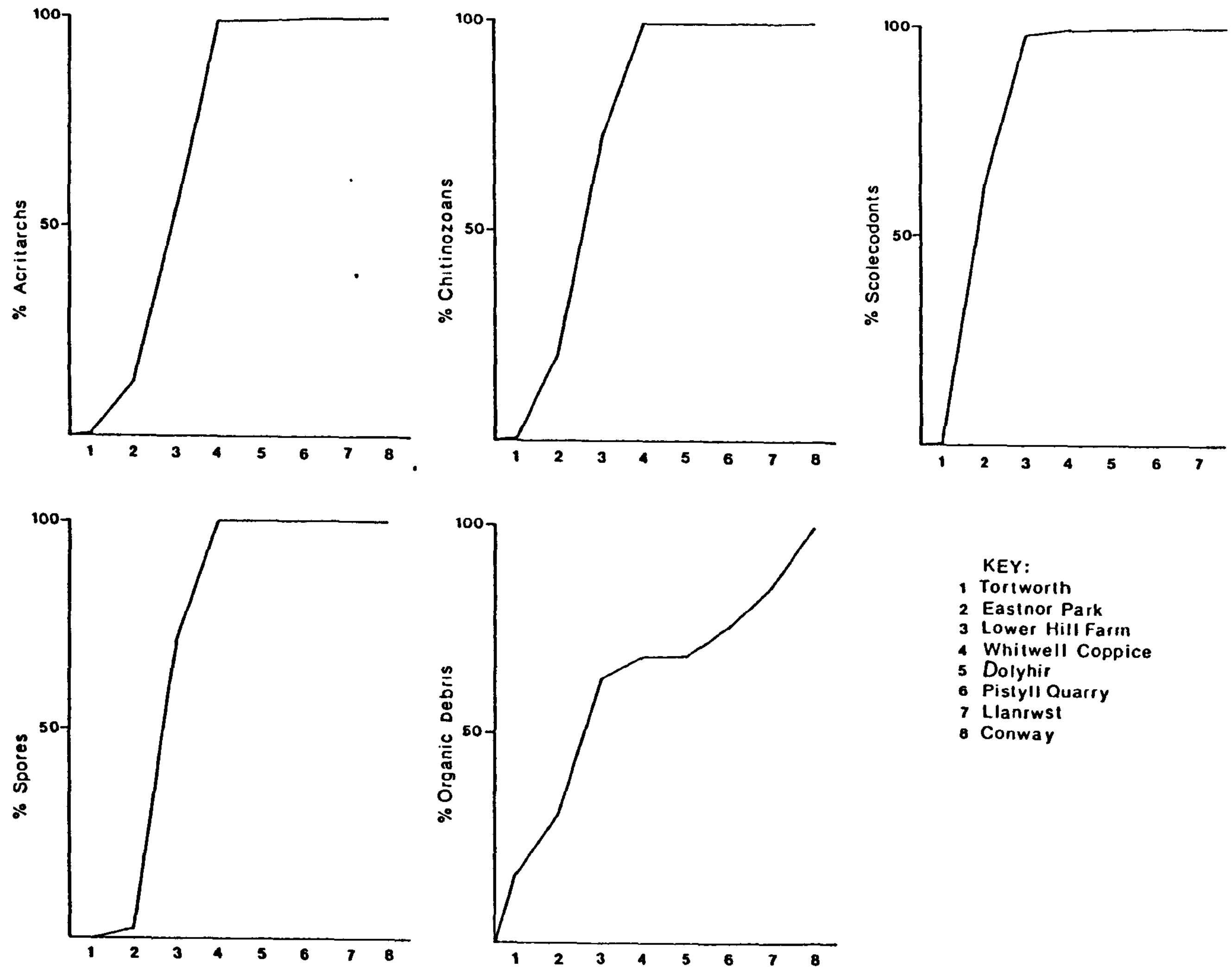


Fig. 45. Cumulative frequency diagrams for average absolute abundances in the studied sections.

Coppice section. The former section accounts for 0.8% while the latter two account for 99.2% of total recovered trilete spores.

Organic debris in the form of Melanosclerites spp., plant cuticle, chitinous hydroids, annular tubing and graptolite fragments are fairly evenly distributed through the studied sections. The highest abundance is recorded from the Lower Hill Farm borehole which accounts for 32.65% of the recorded palynodebris. Organic debris is present in the Tortworth section in the form of annular tubing and some structured cuticle, although it was not recorded in the Dolyhir section. Organic debris in the Eastnor Park borehole accounts for 14.15% of total recorded palynodebris, it is dominated by Melanosclerites spp. and annular tubing, although both graptolite fragments and structured cuticle are present. Whitwell Coppice accounts for only 5.44% of total recorded palynodebris; Melanosclerites spp., annular tubing, chitinous hydroids and graptolite fragments were recorded, but are all relatively rare through the section. Organic debris in the three offshore shelf and basinal sections of Pistyll Quarry, Llanrwst and Conway account for 31.41% of the total recorded palynodebris, the Conway section alone accounts for 14.51%, mainly through abundant annular tubing and Melanosclerites spp.

6.7. Palaeoenvironmental Indices

6.7.a. The Marine Influence Index

Indices using distributional patterns of chitinozoans, acritarchs and spores have been used previously to delineate effects such as marine influence and proximity to the shoreline. The Marine Influence Index used by Traverse (1978) for palynomorphs from recent sediments and modified by Richardson & Rasul (1990) for use with Lower Palaeozoic palynomorphs is:-

$$\frac{\text{Acritarchs + Chitinozoans + Scolecodonts}}{\text{(Above)+ Total Sporomorphs}} \times 100$$

To be meaningful in the present study the index has to be adapted, because trilete spores were recovered from the shelf sediments of the Eastnor Park and Lower Hill Farm boreholes and the Whitwell Coppice section, but were not recovered from the shallow water/nearshore sediments of the Tortworth area. A modified index can be defined as:-

$$\frac{\text{Acritarchs (Not Leiospheres) + Chitinozoans + Scolecodonts}}{\text{(Above) + Total Spores + Thin-Walled Leiospheres}} \times 100$$

The index is not effectively changed because most if not all thin-walled leiospheres are likely to be algal spores (and hence should be included in total sporomorphs). Thin-walled leiospheres seem to have an affinity for shallow water/nearshore environments and therefore their use in the index is appropriate The index now takes into account the fact that spore and therefore plant distribution in the lower and mid-Silurian (when colonisation of the land by plants was in its pioneering stage) depended on a lot of factors, relating to the conditions in which the plants could grow. To simply assume that if a section was palaeoenvironmentally nearshore then the sediments will contain more trilete spores is not neccessarily valid.

The modified Marine Influence Index is applied to the studied sections below (see Table 1). For the shelf sections of Whitwell Coppice and the

Eastnor Park and Lower Hill Farm boreholes where palynomorph abundance is high, four random samples are used in the index calculation, for the other sections all the available data is used. It is realised that from the early to mid-Wenlock there was a gradual deepening phase and that this alone would have had an effect on the palynomorph assemblages and therefore the indices. However, in the context of comparing distinctly different palaeoenvironments of the nearshore-basinal transect which have profound effects on palynomorph assemblages, this gradual deepening is seen as having much less of an effect. Comparative differences are further removed by using data from the whole of a section, or in the case of the shelf sediments (of the Eastnor Park and Lower Hill Farm boreholes and the Whitwell Coppice section) random samples through an entire section.

Sections	Acritarchs	Chitinozoans	Scol	Spores	Leiosph	Index %
Tortworth	74	3	3	-	190	29.26
Eastnor	1039	90	17	1	20	98.20
Lower Hill	1333	597	21	37	5	97.89
Whitwell	1782	332	2	54	7	97.19
Dolyhir	26	29	-	-	55	50.00
Pistyll	110	34	2	-	3	97.98
Llanrwst	163	114	13	-	9	96.98
Conway	50	88	3	-	6	95.83

Table 1. The modified Marine Influence Index for the studied sections.

The indices in Table 1 for the majority of the sections are over 95% indicating a strong marine influence. The two sections with a lower index are the nearershore/shallower water sediments of Tortworth with an index of

29.26% and Dolyhir with an index of 50%. The indices are lower because of the dominance in these sections of thin-walled leiospheres.

6.7.b. The Inshore Index

Another index that has been used is the Inshore Index (Richardson & Rasul 1990). This was defined using just the acritarchs, the index is set out below and is applied to the studied sections in Table 2.:-

$$\frac{\text{Sphaeromorphs + Tasmanites + Micrhystridium}}{\text{(Above) + outer neritic forms (Netro + Acantho + Polygonomorphs)}} \times 100$$

Sections	Sphaeromor	Tasmanites	Michr	Net & Acan	Polyg	Index
Tortworth	190	-	42	23	6	88.88
Eastnor	372	2	327	586	126	49.61
Lower Hill	469	5	171	817	345	26.30
Whitwell	594	29	242	817	723	35.97
Dolyhir	55	-	15	10	1	86.41
Pistyll	545	-	39	44	15 (6.5)	90.82
Llanrws	200	-	28	109	46 (9.6)	61.05
Conway	215	-	7	33	16 (4.4)	81.91

Table 2. The Inshore Index for the different studied sections.

The Inshore Index shown in Table 2 for the nearshore/shallow water deposited sediments of Tortworth and Dolyhir is high (88.88 and 86.41% respectively), due to the abundance of sphaeromorphs and Micrhystridium Deflandre 1937 emend. Staplin 1961 in these sections and the relative paucity of the netromorph, acanthomorph and polygonomorph acritarchs. The index is low in the shelf sections (less than 50% in the Eastnor Park and Lower Hill Farm boreholes and Whitwell Coppice section) due to a relative increase in the abundance of netromorph, acanthomorph and polygonomorph acritarchs. It is worth noting the similarity of the index for the Lower Hill Farm borehole and Whitwell Coppice sections, which although to be expected because of the close proximity of the sections, is a good test for the index. The index for the nearer shore section of the Eastnor Park borehole is higher than in the more offshore sections of the Lower Hill Farm borehole and the Whitwell Coppice section, mainly as a result of the relatively higher abundance of Micrhystridium in the Eastnor Park borehole and of fewer polygonomorphs than in the other two sections.

The index has been calculated for the offshore/basinal sections (of Pistyll Quarry, Llanrwst and Conway) but the results are meaningless as they are distorted by the dominance of small thick-walled leiospheres. Results shown in brackets make a distinction for the index between predominantly 'inshore' sphaeromorphs (thin-walled leiospheres) and predominantly 'offshore' ones (small thick-walled leiospheres). The resulting index is lower, indicating that there may also be a case for modifying the Inshore Index.

In conclusion the two indices are a useful quantitative means of broadly identifying different palaeoenvironments. As well as determining palaeoenvironmental changes vertically in a section (as outlined by Richardson & Rasul 1990) it has been demonstrated that palynomorph assemblages can be taken for a whole section and the determined index compared and contrasted with other sections.

6.8. Palaeoenvironmental conclusions

As Hill & Molyneux (1988, p. 32) mentioned ' the distribution of palynomorph assemblages along the 'inshore-offshore' gradient is unlikely to be a simple response to distance from shore or depth'. Complex hydrodynamic factors such as those described by Colbath (1980) are as likely to be as important for acritarchs and chitinozoans as they are for recent dinoflagellate cysts (Wall et al. 1977). This is illustrated in the present study by certain inconsistencies with past ideas and particularly by the chitinozoans. For instance, sphaerochitinid chitinozoans were recovered mainly from offshore shelf/ basinal samples whereas previously they have been associated with shallow water environments (Laufeld 1974, Dorning 1987). It would appear that generalisations about distributions of palynomorphs (Figs. 42,43) have to be taken as just that, the pattern of assemblage distribution as illustrated and described through this chapter is a complex one and although certain trends can be observed, there is no reason to presume that exactly the same trend will be seen in even the same shelf-basin transect of a slightly different age. This is illustrated in a diagrammatic sketch of selected palynomorph distribution from the late Wenlock carbonate shelf (Dorning 1987, p. 262) where palynomorph distribution shows some inconsistencies compared with that of the studied transect for the early Wenlock shelf and basin. However, broad 'inshore-offshore' trends, if used with caution, can be utilized in palaeoenvironmental interpretations of other sections from Wales and the Welsh Borderland and even further afield, especially if combined with sedimentological information.

The use of Wenlock shelf material for the creation of distributional models is worthwhile for a number of reasons:-

1) The low thermal maturity of the palynomorphs.
2) An abundant and diverse microflora and fauna.
3) An apparently stable shelf.
4) little indication for sedimentological disturbance such as strong currents and reworking of older sediments (and therefore of palynomorphs).

In contrast, the basinal sequences are not good for palynological assemblage analysis. There is evidence for strong NE currents (Cummins 1957) and synsedimentary slumping (Jones 1937; Warren et al. 1984), reflected by reworked Ordovician palynomorphs in some assemblages. Palynomorph abundance is also very low, thermal maturity is high and preservation is very poor.

CHAPTER 7

SYSTEMATIC PALAEONTOLOGY

7.1. Introduction

For the systematic description of the acritarchs The International Code of Botanical Nomenclature is observed, while for the chitinozoans The International Code of Zoological Nomenclature is adhered to.

7.2. Some notes on open nomenclature

For informal qualifiers to the systematics a Robertson Group, report standardisation guide (see Farrar 1984) is used (pp. 6-1 to 6-3). The main points are outlined below:

cf. indicates that the specimen resembles or falls within the known range of variation of the type of the species, without necessarily implying relationship.

aff. inserted before the specific name implies that the specimen is different in some respect(s) from, or falls outside the accepted range of variation of, the species but is possibly related to it.

using an example (Robertson guide p. 6-3):

Cancelloceras cancellatum	[identification certain]
C. cancellatum?	[specific attribution uncertain; used particularly when preservation is poor]
C. cf. cancellatum	[comparable with, but not neccessarily identical to the species]

C. sp. cf. *cancellatum*	[genus certain, species for comparison]
cf. *C. cancellatum*	[nearest for comparison]
?*C. cancellatum*	[whole determination doubtful]
C. aff. *cancellatum*	[with affinity to, but differing from the species]
C. cancellatum trans. to *C. cancellatum*	[nearer the first named but transitional to the second named]
C. sp. between *cancellatum* and *crencellatum*	[showing intermediate characters]
C. sp. nov.	[an undescribed species of the genus]
C. sp.	[identifiable to generic level only]
C. spp.	[more than one unidentified species]
C.?	[species not determinable genus uncertain; usually due to poor preservation]
C.? *sigma*	[species certain, but assignment to genus doubtful]

other related terminology

C. ex gr. *C. cancellatum* [belonging to the species group]

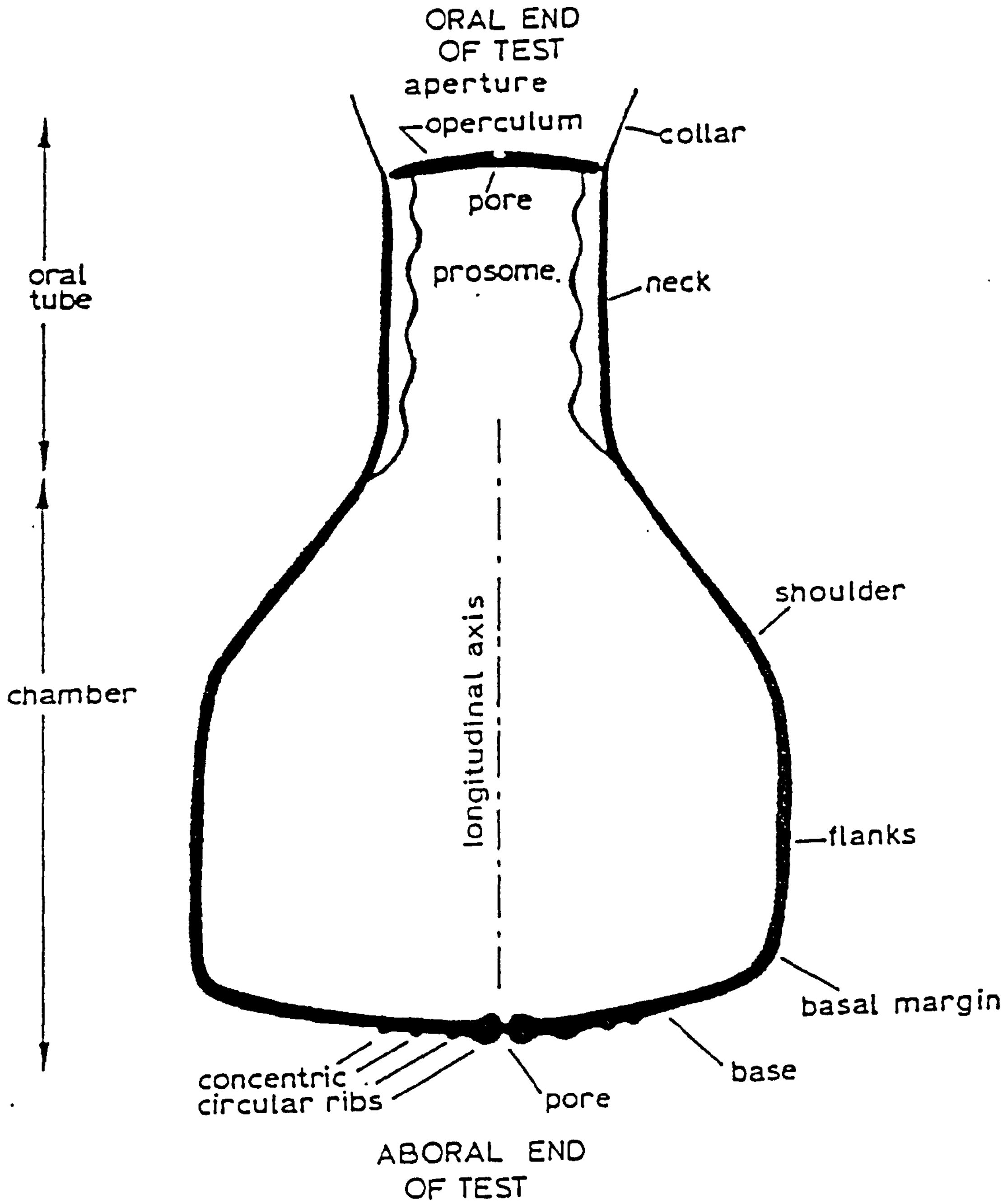


Fig.46 . Major features of the chitinozoan test (after Jansonius & Jenkins 1978).

7.3. Group Chitinozoa

Because of the still uncertain zoological position of the chitinozoa and the less than stable attempts at systematics on the family level, the chitinozoan genera will be dealt with alphebetically as will be the species under each genus.

Descriptive terminology used is that introduced by the *Comission Internationale de Microflore du Palaeozoique* (Combaz et al. 1967), and later refined by Laufeld (1974, p.38). Major morphological features of the chitinozoan test are illustrated in Fig. 46

Genus Ancyrochitina Eisenack 1955a

Type Species: Conochitina ancyrea Eisenack, 1931, pp. 88-89.

Diagnosis: Refer to Eisenack, 1955a, p.163.

Remarks: Species of Ancyrochitina conform in general to Eisenack's diagnosis (1955a, p.163) although his constraint on the number of appendices (4-10) was not found to be suitable in that some specimens possess up to 15.

Ancyrochitina ancyrea (Eisenack 1931)

Pl.1, figs.1,2.

1931 Conochitina ancyrea Eisenack, pp.88,89, fig.2, pl.2, figs. 8-11, pl.4, fig.4.

1937 Conochitina protoancyrea Eisenack, p.224, pl.15, figs. 16-20.

1955a Ancyrochitina ancyrea (Eisenack); Eisenack, pp.163, 164, pl.2, figs. 7-9.

1960 Ancyrochitina ancyrea (Eisenack); Taugourdeau & De Jekhowsky, p. 1218, pl.I, fig. 2-8.

1962 Ancyrochitina ancyrea (Eisenack); Beju & Danet, p.529, pl.1, figs.1-9.

1974 Ancyrochitina ancyrea (Eisenack); Laufeld, pp.38,39, fig.4. (with synonymy to 1971).

1977 Ancyrochitina ancyrea (Eisenack); Eisenack, p.29, Abb. 3-5.

1980 Ancyrochitina ancyrea (Eisenack); Wrona, pp.123-124, pl.24, fig.1.

1981 Ancyrochitina ancyrea (Eisenack); Paris & Chlupáč, p.13.

Remarks

The emended diagnosis of Eisenack 1955a is adhered to, except that forms with appendices branching in an 'antler like or irregular way' are not included in Ancyrochitina ancyrea. This leaves forms whose appendices branch simply and distally; the inclusion of these forms only in A. ancyrea was suggested by Laufeld 1974, complexly branched specimens being accomodated in Ancyrochitina gutnica Laufeld 1974.

Dimensions: Populations from the Wenlock type area and the Eastnor Park borehole (in microns): length 98-115, width at the basal margin 70-78, width of the aperture 38-43, length of appendices 37-52. Number of specimens measured 15.

Material: 196 specimens.

Occurrence: Ancyrochitina ancyrea was recovered from the Buildwas and Coalbrookdale Formations of the Wenlock type area, and the Woolhope Limestone of the Eastnor Park borehole.

Ancyrochitina ancyrea has previously been recovered from Silurian and Lower Devonian strata in North Africa (Taugourdeau & De Jekhowsky 1960) and in Poland (Wrona 1980); from lower Wenlock to lower Ludlow strata in

Gotland (Eisenack 1937, 1955a; Laufeld 1974) and from across the Silurian/Devonian boundary at the Klonk section in Bohemia (Paris & Chlupáč 1981). Eisenack (1977) recovered it from the Wenlock Limestone at Dudley in the English West Midlands. Dorning (1981b) records its range as Llandovery to upper Ludlow in the Wenlock type area.

Ancyrochitina cf. diabolus Eisenack 1937, nom. correct. Laufeld 1974.

Pl.1, fig.6; Pl.7, fig.6.

cf. 1937 Conochitina diabolo Eisenack, pp.223,224, pl.15, figs. 21-22.

cf. 1955a Ancyrochitina diabolo (Eisenack); Eisenack, p.176, pl.3, fig.4.

cf. 1964a Ancyrochitina diabolo (Eisenack); Eisenack, p.326.

cf. 1968a Ancyrochitina diabolo (Eisenack); Eisenack, p.173, pl.28, figs. 1-6; pl.29, figs. 9-12.

cf. 1974 Ancyrochitina cf. diabolus (Eisenack); Laufeld, nom. correct. pp. 43,45, fig.8.

cf. 1977 Ancyrochitina diabolus (Eisenack); Eisenack, p.29, Abb 6.

Remarks

Ancyrochitina diabolus is a morphologically distinct species possessing a cylindro-spheroidal vesicle with a broadly rounded basal margin which has 3-7 horn like appendices; the appendices are commonly curved in an aboral direction and are hollow. The neck is slightly widened at the aperture, which is straight and unfringed.

Ancyrochitina cf. diabolus differs from Ancyrochitina diabolus in the possession of inflated 'bulb' like terminations to the appendices, which is in contrast to more typical tapering appendices. Observed specimens bear a resemblance to Ancyrochitina cf. diabolus Laufeld 1974 in that vesicle and appendix shape are similar, although the observed specimens are better preserved than the specimens he illustrates. Ancyrochitina pachyderma Laufeld 1974 has shorter processes which are triangular in outline.

Dimensions: Populations from the Lower Hill Farm borehole (in microns): length 135-146, width at the basal margin 59-68, width of the narrowest part of the vesicle 20-25, width of the aperture 23-26. Number of specimens measured 6.

Material: 12 specimens.

Occurrence: Ancyrochitina cf. diabolus was recovered from the middle Coalbrookdale Formation of the Lower Hill Farm borehole (late Sheinwoodian to early Homerian).

Eisenack (1937) first described Ancyrochitina diabolus from Ludlow strata of the north German Baltic area. He did not find it in Gotland, nor did Laufeld (1974) who only found 'forerunners' which he compared to A. diabolus; these 'forerunners' in Gotland had a range from the top of Wenlock into the Ludlow.

Eisenack (1977) recovered Ancyrochitina diabolus from the middle nodular beds (late Wenlock) of Dudley in the English West Midlands.

Ancyrochitina gutnica Laufeld 1974

Pl.1, figs.7,8; Pl.7, figs.1,4.

1974 Ancyrochitina gutnica Laufeld, pp.45,47, fig.9.

1981 Ancyrochitina gutnica Laufeld; Aldridge et al. p.21, pl.2.3, fig.9.

Remarks

The original diagnosis of Laufeld 1974 is strictly adhered to and therefore forms that possess characteristic branched appendices but lack curved spines on the neck are not placed in Ancyrochitina gutnica. A morphological variation that has been allowed is the amount of branching of the appendices, (first to third order) because on a single specimen it is possible to have different appendices branching to a different order.

Ancyrochitina ancyrea Eisenack 1964 has a flatter base and less complexly branched processes.

Dimensions: Populations from the Wenlock type area, the Eastnor Park borehole, North Wales and Dolyhir (in microns): length 113-125, width at the basal margin 62-75, width of aperture 30-36, maximum length of appendices 36. Number of specimens measured 15.

Material: 641 specimens.

Occurrence: Ancyrochitina gutnica was recovered from the Buildwas and Coalbrookdale Formations of the Wenlock type area, the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole, and the lower Denbigh grits of North Wales; it also occurs sporadically in the Dolyhir Limestone of the Old Radnor area (Sheinwoodian to Homerian).

Laufeld (1974) first recovered Ancyrochitina gutnica from the early to late Wenlock of Gotland. Dorning (1981b) recovered it from the Coalbrookdale Formation and the Wenlock Limestone of the Wenlock type area.

Ancyrochitina pachyderma Laufeld 1974

Pl.1, fig.5; Pl.7, fig.2.

1974 Ancyrochitina pachyderma Laufeld, pp. 45-47, fig.10.

Remarks

Laufeld's (1974, p.45) diagnosis and description of the species needs few additions, although there is a difference in appendix size in my material; some of the studied specimens possess short wide appendices which are triangular in outline, while other specimens have appendices with a narrower base. All appendices are characteristically hollow and appear to be composed of homogenous spongy tissue.

Both Ancyrochitina gutnica Laufeld 1974 and A. ancyrea (Eisenack 1931) possess branched processes in contrast to the unbranched processes of A. pachyderma.

Dimensions: Populations from the Lower Hill Farm borehole, and Eastnor Park borehole (in microns): length 85-115, width at basal margin 60-75, width of aperture 27-35, width of appendices at basal margin 9-17, length of appendices 16-36. Number of specimens measured 9.

Material: 26 specimens.

Occurrence: *Ancyrochitina pachyderma* was recovered from the Buildwas Formation of the Lower Hill Farm borehole, and the Woolhope Limestone of the Eastnor Park borehole (Sheinwoodian).

Previously *Ancyrochitina pachyderma* has been recovered from the upper Llandovery and early Wenlock of Gotland (Laufeld, 1974). Dorning (1981b) recorded *A. pachyderma* from the Purple Shales and Buildwas Formation of the Wenlock type area (upper Llandovery - early Wenlock).

Ancyrochitina primitiva Eisenack 1964a

Pl.1, figs.3,4.

1964a *Ancyrochitina primitiva* Eisenack, pp. 323-324, pl.27, figs. 1-6, 8-14; pl.28, figs. 1-5.

1968a *Ancyrochitina primitiva* Eisenack; Eisenack, p.172, pl.24, figs. 6, 13-15; pl.27, figs. 5-9,10,11.

1970 *Ancyrochitina primitiva* Eisenack; Eisenack, p.307, fig. 1M, 2 A-B.

1971 *Ancyrochitina* cf. *primitiva* Eisenack; Laufeld, pl.1:E.

1977 *Ancyrochitina primitiva* Eisenack; Eisenack, p.29.

1981 *Ancyrochitina primitiva* Eisenack; Paris, p.283, pl.20, fig.5.

Remarks

In his original diagnosis Eisenack (1964a, p.323) stated that *Ancyrochitina primitiva* is characterised by a flat or slightly concave base and by its 4-

9, fairly short, thick based, unbranched appendices; he further pointed out that the appendices were perpendicular to the longitudinal axis or curved in the oral direction and that the sub-cylindrical neck lacks or is provided with spines. To this diagnosis he added that the species show such great variation that each of the above mentioned characteristics may be absent.

Studied specimens conform generally to Eisenack's original diagnosis although differences such as aboral curvature of the appendices, and vesicles with convex bases were encountered; Laufeld (1974, p.47) suggested that these differences can be accounted for purely by preservational state. The commonest forms of A. primitiva studied did not possess spines on their necks, having only simple hollow appendices which varied in number from 4-7.

Ancyrochitina pachyderma Laufeld 1974 possesses wider based (triangular) processes.

Dimensions: Populations from the Wenlock type area (in microns); length 100-108, width at basal margin 87-94, width of aperture 22-27, maximum length of appendices 12-16. Number of specimens measured 13.

Material: 486 specimens.

Occurrence: Ancyrochitina primitiva in the studied sections has a long stratigraphical range (early Sheinwoodian to early Homerian) occurring in the Buildwas and Coalbrookdale Formations of the Wenlock type area; numerically it is most abundant in the Buildwas Formation where it can account for up to 40% of the chitinozoan assemblage in a single sample.

Ancyrochitina primitiva has previously been recovered from the late Llandovery to mid Ludlow of Gotland (Eisenack 1964a; Laufeld 1974), the Wenlock and Ludlow of Estonia (Eisenack 1971), and the Wenlock of Podolia (Laufeld 1971). Eisenack (1977) recovered A. primitiva from the Wenlock Limestone of Dudley in the English West Midlands; Dorning (1981b) recorded its range in the Welsh Borderlands as Llandovery to late Ludlow.

Genus *Angochitina* Eisenack 1931 emend. 1968

Type species: *Angochitina echinata* Eisenack 1931.

Diagnosis: Refer to Eisenack 1968, p.177.

Angochitina longicollis Eisenack 1959 nom. correct. Laufeld 1974

Pl.2, figs.1,2; Pl.7, fig.3.

1959 *Angochitina longicollis* Eisenack, p.13, pl.2, figs. 8-9.

1974 *Angochitina longicollis* Eisenack; nom. correct. Laufeld, pp. 56-57, fig.19, (with synonymy to 1971).

1978 *Gotlandochitina* ? sp.B Verniers & Rickards, p.156, pl.1, figs. 5,6,7.

1981 *Angochitina longicollis* Eisenack; Verniers, pp. 171-172, pl.1, fig.13.

1982 *Angochitina longicollis* Eisenack; Verniers, pp. 17-19, pl.9, figs. 230-237.

Remarks

In the most oral part of the neck of *Angochitina longicollis* the spinose ornamentation is seen to decrease in size quite abruptly; the basal parts of the spines are hollow and are relatively wide were they join the vesicle, some adjacent spines coalesce (lambda spines) while others branch simply and distally. Verrucae and small spines are randomly distributed between the larger spines. The length and width of the neck appears to be a variable character with some specimens possessing relatively shorter and wider necks; this variation has also been noted by Verniers (1982, p.19). None of the observed specimens showed any alignment of the spines into longitudinal rows and therefore this species is quite distinct from any described species of *Gotlandochitina*.

Ancyrochitina echinata Eisenack 1931 possesses longer spines and a shorter neck than *A. longicollis*.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns). Length 215-240, greatest width of vesicle 74-86, width of aperture 42-49, maximum length of spines 10. Number of specimens measured 13.

Material: 75 specimens.

Occurrence: In the Wenlock type area *Angochitina longicollis* was only observed in the lowest Buildwas Formation of the Lower Hill Farm borehole; it was also recovered from the Woolhope Limestone of the Eastnor Park borehole.

Angochitina longicollis has previously been recovered from the late Llandovery to early Wenlock of Gotland (Eisenack 1964,1968; Taugourdeau & De Jekhowsky, 1964; Laufeld, 1971, 1974). It also has a similar range in Estonia (Kaljo 1970), in Podolia (Laufeld 1971) and in Belgium (Verniers 1982). Dorning (1981b) recorded *A. longicollis* from the upper Llandovery of the Welsh Borderlands.

Genus *Calpichitina* Wilson & Hedlund 1964

Type Species: by original designation *Calpichitina scabiosa* Wilson & Hedlund 1964.

Diagnosis: Refer to Wilson & Hedlund 1964, p. 161.

Remarks: *Calpichitina* differs from *Desmochitina* (Eisenack, 1931) in that in the former the longitudinal axis of the chitinozoan is shorter than the transverse axis and therefore the chitinozoan tends to sit on the glass slide aperture facing up or down; with *Desmochitina* the longitudinal axis is longer than the transverse and the chitinozoan tends to be observed in the normal fashion of the chitinozoans, that is side on. *Hoegisphaera* Staplin emend. Legault 1973a does not possess the collar or oral membrane observed on species of *Calpichitina*.

Paris 1981 (p.181) distinguishes two sub-genera of Calpichitina, these being Calpichitina (Densichitina) and Calpichitina (Calpichitina), the distinguishing feature separating the two is the mucron which has been identified in the chains seen in the former, the mucron attaches the aboral part of one chitinozoan vesicle to the operculum of the next vesicle in the chain.

Calpichitina (Densichitina) densa (Eisenack 1962)

Pl.3, fig.10; Pl.8, figs.7,8.

1962a Desmochitina densa Eisenack, pp. 311-312, pl.17, fig.14.

1964a Desmochitina densa Eisenack; Eisenack, p.348, pl.22, figs. 1-3.

1966a Desmochitina densa Eisenack; Taugourdeau, pp. 34-35, pl.2.

1971 Desmochitina densa Eisenack; Laufeld, p. 295, pl.1:A.

1974 Desmochitina densa Eisenack; Laufeld, p.77, fig.39.

1981 Calpichitina (Densichitina) densa (Eisenack); Paris, p.131.

1985 Calpichitina (Densichitina) densa (Eisenack); Hill et al., pl. 14, figs. 7,14.

1988 Desmochitina densa Eisenack; McClure, pl. VII, fig.3.

Remarks

Laufeld (1974) remarked that Calpichitina (Densichitina) densa is commonly encountered as twins or chains. In my material chains and twins do occur but are less frequent than single specimens. The common position of observed specimens is looking down on the aperture which is circular. The few chains observed show typical attachment of the base of a vesicle to an operculum (by a mucron). In single specimens with opercula the centres are darker and are presumably thicker indicating the attachment point. The flange-like aboral part of the operculum referred to by Laufeld (1974) is not obvious in studied specimens but this is probably due to only a few intact opercula being preserved. Laufeld (1974) stated that style of operculum 'excludes the supposition that the operculum in C. (Densichitina) densa was moveable and was opened and closed repeatedly'; he saw the operculum 'as an effective seal constructed for protecting the organism living inside the vesicle'. It is presumed from the lack of specimens in the present study possessing intact opercula, and from the presence of only a few chains, that the palaeoenvironmental conditions must have been ideal for 'hatching'.

Calpichitina (Calpichitina) acollaris (Eisenack, 1959) possesses a sculptured vesicle wall in contrast to the unornamented vesicle of C. (Densichitina) densa and is not seen to form chains (Laufeld 1974, p. 76).

Dimensions: Populations from the Wenlock type area and the Eastnor Park borehole (in microns); length 53-67, width 64-87, interior width of aperture 30-37. Number of specimens measured 10.

Material: 40 specimens.

Occurrence: Calpichitina (Densichitina) densa was encountered in the lower and middle Buildwas Formation of the Lower Hill Farm borehole, and the Woolhope Limestone of the Eastnor Park borehole. C. (Densichitina) densa has a peak of abundance in the mid Buildwas Formation were it can account for over 50% of a chitinozoan assemblage.

C. (Densichitina) densa has previously been recorded from Llandovery to early Wenlock strata in Gotland (Eisenack 1962a, 1964a; Laufeld 1974), and from strata of similar age in Spain (Cramer 1964), Nova Scotia (Cramer 1970a) and Podolia (Laufeld 1971).

Dorning (1981b) previously recorded C. (Densichitina) densa from the Llandovery Purple Shales in the Wenlock type area; its range is extended here into the early Wenlock.

Genus Cingulochitina Paris 1981

Type species: by original designation Desmochitina cingulata Eisenack 1937.

Diagnosis: Refer to Paris, 1981, p. 164.

Remarks

In the diagnosis of Cingulochitina Paris (1981) distinguishes it from species of Linochitina in that the former has a 'true skirt' and not a simple pointed aboral border as found in the latter. It is of interest to note that Paris did not recognise any coexistence between forms with and without carina; this observation is corroborated in the present study where the stratigraphical range of Linochitina cf. erratica (Eisenack, 1931) is distinct from that of Cingulochitina cingulata, but there is a continuation from L. cf. erratica to C. cingulata forming almost one continous range. No gradational forms with reduced carina were observed and there is apparently a rapid change to forms like C. cingulata possessing a distinct carina. It therefore does seem a distinct possibility as Paris suggests (1981, p.165) that Cingulochitina could be derived from Linochitina *sensu stricto*.

Cingulochitina cingulata (Eisenack 1937)

Pl.2, figs.5,7; Pl.7, figs.5,8.

1937 Desmochitina cingulochitina Eisenack, p.220, pl.15, figs. 6-7.

1966a Eremochitina ? cingulata (Eisenack); Taugourdeau, p.38, pl.1, fig.4.

1968a Linochitina cingulata (Eisenack); Eisenack, pp. 170-171, pl.24, figs. 12,16; pl.29, figs. 29-32; pl.31, fig.18.

1974 Linochitina cingulata (Eisenack); Laufeld, p.97, fig.57.

1978 Linochitina cingulata (Eisenack); Verniers & Rickards, pl.2, fig.14.

1981 Cingulochitina cingulata (Eisenack); Paris, p.164.

1982 Cingulochitina cingulata (Eisenack); Verniers, pp. 20-22, pl.6, fig.122, pl.7, fig.148, 157-169.

Remarks

The most distinctive morphological feature of Cingulochitina cingulata is its carina around the basal margin which forms a wide skirt when well developed. The aperture of observed specimens is typically flared and in extreme forms this could be referred to as a collar. The ornamentation is variable from forms with a smooth vesicle to those possessing a roughly scabrate or verrucose ornament. Twins and chains are very common.

Cingulochitina convexa (Laufeld 1974) possesses a more convex base and a carina that is not as well developed as C. cingulata.

Dimensions: Populations from the Wenlock type area, the Eastnor Park borehole, Dolyhir and North Wales (in microns). length 80-93, width at basal margin 45-59, width of aperture 35-44. Number of specimens measured 22.

Material: 3678 specimens.

Occurrence: A cosmopolitan species occurring in the Coalbrookdale Formation of the Wenlock type area and of the Eastnor Park borehole, the Dolyhir Limestone of the Old Radnor area, the lower Denbigh Grits of North Wales and from the Nant-ysgollon Shales of Central Wales. Cingulochitina cingulata is a very abundant species especially in the middle Coalbrookdale Formation where it can account for up to 75% of a chitinozoan assemblage; this dominance has been previously noted from the middle part of the Coalbrookdale Formation of the Wenlock type area (Aldridge et al., 1981. p.21).

Cingulochitina cingulata has previously been recorded as having a Caradocian to Devonian stratigraphical range. Unfortunately a lot of publications recording the species do not contain illustrations or figures of the species making synonymy difficult. Laufeld (1974) restricted the range of C. cingulata *sensu stricto* to mid to late Venlock, this was corroborated by Verniers (1982) who found it to have a similar range in the Mehaigne area of the Brabant Massif, Belgium. Dorning (1981b) recovered C. cingulata from the Coalbrookdale Formation and the lower part of the Much Wenlock Limestone Formation of the Wenlock type area.

Genus Conochitina Eisenack 1931

Type species: by original designation Conochitina claviformis Eisenack 1931.

Diagnosis: Refer to Eisenack 1968, p.158.

Remarks: Conochitina was erected by Eisenack in 1931, the genus was restricted by the same author in 1955a and 1965. Some species of Conochitina have previously been included in Bursachitina Taugourdeau 1966. Eisenack (1968a, p.158) disagreed and ranked Bursachitina as a subgenus of Conochitina also changing the diagnosis. In 1970 Jansonius pointed out that Bursachitina is a junior synonym of the genus Eisenackitina Jansonius 1964.

In the present study the genus Eisenackitina as defined by Jansonius (1964, p.912) is used, the remaining Conochitina (s.l.) species are referred to as Conochitina.

Conochitina argillophila Laufeld 1974

Pl.2, fig.3; Pl.8, fig.1.

1974 Conochitina argillophila Laufeld, p.59, fig.22.

Remarks

The studied specimens conform generally to the diagnosis given by Laufeld (1974) except that the overall dimensions are a little larger. As Laufeld suggested, some of the specimens possess 'shallow convex bases while others possess a base that protrudes more'; this combined with the relatively large difference in apertural width could be due to differences in compressional modes.

Conochitina tuba Eisenack 1932 is longer with straighter flanks.

Dimensions: Populations from the Wenlock type area (in microns): length 143-165, width at the basal margin 55-76, width of the aperture 39-55. Number of specimens measured 11.

Material: 102 specimens.

Occurrence: Conochitina argillophila was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area. It has previously been recorded from the early Wenlock of Gotland (Laufeld 1974). Dorning (1981b) recovered it from the middle Buildwas Formation to the top of the Coalbrookdale Formation in the Wenlock type area.

Conochitina armillata Taugourdeau & De Jekhowsky 1960

Pl.2, figs. 4,6.

1960 Conochitina armillata Taurgourdeau & De Jekhowsky, p.1222, pl.3, fig.44, 45,46.

1964 Conochitina armillata Taurgourdeau & De Jekhowsky; Taurgourdeau & De Jekhowsky, pl.3, fig.30.

1968 Conochitina armillata Taurgourdeau & De Jekhowsky var. minor Lister var. nov. p.158, pl.27, figs. 1-8.

1981 Conochitina armillata Taurgourdeau & De Jekhowsky; Verniers, p.172, pl.1, fig.8.

1982 Conochitina armillata? Taurgourdeau & De Jekhowsky; Verniers, pp.29-31, pl.2, figs. 20-27.

Remarks

Specimens of Conochitina armillata are typically cylindro-conical forms; the vesicle has its maximum width at about one third of the total length from the base, above which is a constriction and a long cylindrical neck. The vesicle is typically smooth and unornamented. The basal margin of C. armillata is rounded, and the base flat to slightly convex, some specimens possess a concave centre to their base. In the original diagnosis the length of the holotype is 270 microns; this is found in the specimens studied to be an upper limit for length. There is a variance in the population from short wide specimens to long thin ones, although all have the characteristic constriction in the flanks. Verniers (1982) related C. armillata to a group of chitinozoans including C. tuba and S. elenitae; observed specimens of C. armillata are quite distinct morphologically from other described species of Conochitina.

Dimensions: Populations from the Venlock type area (in microns): length 150-268, width at basal margin 65-76, width of aperture 48-69. Number of specimens measured 8.

Material: 22 specimens.

Occurrence: Conochitina armillata occurs in the mid Coalbrookdale Formation of the Lower Hill Farm borehole (late Sheinwoodian to early Homerian); its previously recorded range is middle to late Venlockian in Belgium (Verniers 1982) and late Venlockian to Ludlovian in North Africa (Taugourdeau & De Jekhowsky 1960). In samples from the Welsh Borderlands it was recovered from the Venlock Limestone and Middle Elton beds by Lister (1970, p.22) and this has a stratigraphical range of late Venlock to early Ludlow.

Conochitina granosa Laufeld 1974

Pl.8, figs.3,5.

1974 Conochitina granosa Laufeld, pp.61-62, fig.24.

Remarks

The specimens studied generally conform to Laufeld's (1974, p.61) diagnosis and description; one difference is the presence of a low granular ornamentation on the base of the vesicle; Laufeld refers to a verrucate ornamentation on the vesicle but states that the base is unornamented.

Conochitina granosa is easily distinguished from C. intermedia Eisenack 1955a and similar species by the location of the widest part of the vesicle, about a third of the vesicle length oralward of the basal margin, further the flanks are curved markedly in C. granosa whereas the flanks of C. intermedia are almost straight.

Dimension: Populations from the Lower Hill Farm borehole (in microns): length 120-150, width at basal margin 53-68, width of aperture 42-50, greatest width of vesicle 75-80. Number of specimens measured 5.

Material: 5 specimens.

Occurrence: Conochitina granosa was recovered from the Coalbrookdale Formation (Homerian) of the Lower Hill Farm borehole.

Previously Conochitina granosa has been recovered from the lower to middle Ludlow of Gotland (Laufeld 1974); Dorning (1981b) recorded its presence only in the Leintwardine beds (middle Ludlow) of the type Ludlow of the Welsh Borderlands.

Conochitina pachycephala Eisenack 1964

Pl.3, figs.1,2.

1964a Conochitina pachycephala Eisenack, p.315, pl.26:6, figs. 4-8.

1967 Conochitina sp. Jansonius, pl.1, figs. K,L,N,O.

1968a Conochitina pachycephala Eisenack; Eisenack, p.344.

1974 Conochitina pachycephala Eisenack; Laufeld, p.69, fig. 31.

1977 Conochitina pachycephala Eisenack; Eisenack, p.30, fig.7.

1981 Conochitina pachycephala Eisenack; Paris, p.182, fig. 83a; pl.19, fig. 15-17.

Remarks

Conochitina pachycephala is a long thin sub-cylindrical species of chitinozoan possessing a characteristic constriction of the vesicle just oralward of the basal margin. The vesicle wall is smooth and thins towards the aperture; this thinning has led to collapse of the apertural area in most of the studied specimens. Jansonius (1967, pl.1: K,L,N) demonstrated that the oral part of the neck can be wide and lip-like, although this feature was not observed even on the complete specimens studied.

Conochitina proboscifera (Eisenack 1937) has a longer wider vesicle that does not possess a constriction.

Dimensions: Populations from the Lower Hill Farm borehole (in microns): length 502-653, width at basal margin 69-80, width of aperture 42-51. Number of specimens measured 5.

Material: 54 specimens.

Occurrence: Conochitina pachycephala was recovered from the Coalbrookdale Formation (Sheinwoodian) of the Lower Hill Farm borehole.

It has previously been recorded from the mid to late Wenlock of Gotland (Laufeld 1974) and the early Wenlock of Estonia (Kaljo 1970).

In the type Wenlock area of the Welsh Borderlands C. pachycephala has a previously recorded range of mid Wenlock to early Ludlow (Coalbrookdale Formation, Wenlock Limestone and Elton Beds; Dorning 1981b); Eisenack

(1977) had earlier reported its occurrence from the Wenlock Limestone of Dudley in the West Midlands.

Conochitina proboscifera Eisenack 1937

Pl.3, fig.4; Pl.8, fig.4.

1937 Conochitina proboscifera Eisenack, p.225, pl.15, figs. 4,5.

1959a Conochitina proboscifera Eisenack; Eisenack, pp.5-6, pl.3, figs. 1,2.

1964a Conochitina proboscifera Eisenack; Eisenack, pp.313-314, pl.26, figs. 1,2.

1964b Conochitina proboscifera Eisenack; Eisenack, pp. 859-860, pl.1, figs. 10-13; pl.2, figs. 14-21; pl.3, figs. 22,25; pl.4, figs. 38-39.

1966a Conochitina proboscifera Eisenack; Taugourdeau, p.35, pl.2, figs. 43-44.

1968a Conochitina proboscifera Eisenack; Eisenack, p.159, pl.24, fig.4; pl.25, figs. 1-2; pl.31, fig.2.

1970 Conochitina proboscifera Eisenack; Eisenack, p.305, fig.1: A,C,D.

1971 Conochitina proboscifera Eisenack; Laufeld, p.295, pl.1: H.

1972b Conochitina proboscifera Eisenack; Eisenack, pl.34: 29.

1974 Conochitina proboscifera Eisenack; Laufeld, pp. 70-71, figs.32-34.

1982 Conochitina proboscifera Eisenack; Verniers, pp. 35-36, pl.1, figs. 1-17.

Remarks

Laufeld (1974) observed a great variation in overall shape of Conochitina proboscifera and distinguished two types (using particularly length : width ratios) from the populations of typical forms, he termed these forma truncata and forma gracilis. In the present study only the typical forms and the forma gracilis were encountered.

The length : width ratio of 1: 6-8 for Conochitina proboscifera as defined by Laufeld (1974, p.70) is used in the present study; observed specimens have an almost cylindrical vesicle which is unornamented, and possess a flat to rounded base which may have a basal process. Chains of C. proboscifera were not found. In some of the Denbigh Grits samples large specimens of C. proboscifera are associated with large robust scolecodont specimens.

Dimensions: Populations from the Wenlock type area, the Eastnor Park borehole, North and Central Wales (in microns): length 342-721, width at basal margin 82-109, width of aperture 63-85. Number of specimens measured 15.

Material: 550 specimens.

Occurrence: A cosmopolitan species with a relatively long stratigraphical range (early Sheinwoodian to early Homerian) occurring in the Buildwas and Coalbrookdale formations of the Wenlock type area, the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole, the Dolyhir Limestone, the Denbigh Grits and the Lower Nantglyn Flags of North Wales and the Nant-ysgollon shales of Central Wales.

Conochitina proboscifera has previously been recorded from the upper Llandovery and lower Wenlock of Gotland (Laufeld 1971, 1974), Estonia (Eisenack, 1968), Podolia (Laufeld 1971), France (Paris et al., 1980; Paris, 1981) and Belgium (Verniers 1982); it has also been recorded in the type Wenlock of the Welsh Borderlands by Dorning (1981b) who found it in the Buildwas and Coalbrookdale formations.

Conochitina proboscifera Eisenack 1937 forma *gracilis* Laufeld 1974

Pl.3, fig.5.

1974 *Conochitina proboscifera* Eisenack 1937 forma *gracilis* Laufeld, p.72, fig. 34: A-C.

Remarks
As Laufeld (1974, p.72) suggested populations have been referred to forma *gracilis* when the length : width ratio is 1: 9-10, specimens observed are characterized by a continous tapering of the vesicle in an oral direction, and an elongated and rounded base.

Dimensions: Populations from the Wenlock type area (in microns): length 850-962, width at basal margin 89-122, width of aperture 75-87. Number of specimens measured 7.

Material: 30 specimens.

Occurrence: forma *gracilis* occurs in the Buildwas and Coalbrookdale formations of the Wenlock type area, its range overlapping with more typical forms. in Gotland it has been recovered from late Llandovery to early Wenlock strata. This form is less common than typical forms of *C. proboscifera*.

Conochitina tuba Eisenack 1932

Pl.3, figs.3,6; Pl.8, fig.2.

1932 *Conochitina tuba* Eisenack, p.271, pl.12, figs. 8-10.

1962a *Conochitina tuba* Eisenack; Eisenack, pp. 294-295, pl.14, fig.2.

1964 *Conochitina tuba* Eisenack; Eisenack, p.316, pl.26, fig.13.

1974 *Conochitina tuba* Eisenack; Laufeld, pp. 72-73, fig.36.

1978 Conochitina tuba Eisenack; Verniers & Rickards, pl.2, fig.7.

1981 Conochitina tuba Eisenack; Verniers, pl.1, fig.5.

1981 Conochitina tuba? Eisenack; Paris, pp. 186-187, fig.83c; pl.20, figs. 13-16.

1982 Conochitina tuba Eisenack; Verniers, pl.3, figs. 51-54.

Remarks

In the studied populations of Conochitina tuba the vesicle is sub-cylindrical, the flanks of the body are generally straight, and the basal margin is broadly to bluntly rounded, possessing sometimes a short but wide basal process. The vesicles are typically unornamented, unlike some specimens from the Wenlock of Gotland which possess a low rugose ornamentation (Laufeld 1974, p.73), or have a covering of minute hairs (Eisenack 1962a, p.295). There is quite a variation in overall length of the vesicle of C. tuba; the range in length recorded by Laufeld (1974, p.73) is used to define the species distinguishing it from the smaller but similar vesicle of C. argillophila.

Dimensions: Populations from the Wenlock type area, the Eastnor Park borehole and North Wales (in microns): length 216-330, width of basal margin 68-93, width of aperture 60-78. Number of specimens measured 11.

Material: 122 specimens.

Occurrence: Conochitina tuba was recovered from the upper Buildwas to middle Coalbrookdale Formation of the Wenlock type area, the Woolhope Limestone of the Eastnor Park borehole, and the Denbigh Grits of North Wales.

Previously Conochitina tuba has been recovered from the middle Wenlock to Ludlow of Gotland (Laufeld 1974), and from the middle to late Wenlock of Estonia (Kaljo 1970), and Belgium (Verniers 1982). C.tuba has previously been recovered from strata of the Millichope area of Shropshire (Lister 1968), where it was found in the top of the Wenlock Limestone, in the Elton

Beds and in the Lower Bringewood Beds (upper Wenlock to mid Ludlow); its range in the Wenlock type area as recorded by Dorning (1981b) is mid-Wenlock to Ludlow.

Conochitina visbyensis Laufeld 1974

Pl.3, figs.7,8; Pl.8, fig.6.

1974 Conochitina visbyensis Laufeld, pp.73,74, fig.37.

1981 Conochitina visbyensis Laufeld; Aldridge et al. pl. 2.1, fig. 12.

Remarks

The studied specimens generally conform to Laufeld's original diagnosis (1974, p.74). One minor difference is that the oral most parts of the vesicle are typically more flared than on Laufeld's illustrated specimens; in addition, the rugose ornamentation tends to be entire over the vesicle surface instead of being 'well developed only in the aboral part of the vesicle'. Chains are present but are not common.

Conochitina tuba Eisenack 1932 has a longer vesicle which is unornamented.

Dimensions: Populations from the Lower Hill Farm borehole and Eastnor Park borehole (in microns): length 89-105, width of basal margin 45-56, width of aperture 31-44. Number of specimens measured 12.

Material: 115 specimens.

Occurrence: Conochitina visbyensis was recovered from the lower Coalbrookdale Formation of the Eastnor Park borehole.

C. visbyensis has been recorded from the early Wenlock of Gotland (Laufeld 1974). In the Wenlock type area it has previously been recovered from the Purple Shales and Buildwas Formation (late Llandovery to early Wenlock; Dorning 1981b); it has also been recovered from the Woolhope Limestone (early Wenlock) of the Woolhope inlier (Hereford and Worcester) (Aldridge et al. 1981).

Genus *Eisenackitina* Jansonius 1964

1964 *Eisenackitina* Jansonius, p. 912.

1966 *Bursachitina* Taugourdeau, p. 72.

Type Species: *Eisenackitina castor* Jansonius 1964.

Diagnosis: Refer to Jansonius, p. 912.

Remarks: In the diagnosis of *Eisenackitina* Jansonius refers to a lip that is very much reduced, usually absent; although this is normally the case, one of the observed species (*Eisenackitina* sp.A) possesses a well defined collar.

Eisenackitina cf. *lagenomorpha* (Eisenack 1931)

Pl.3, figs.9,11; Pl.9, fig.4.

cf. 1931 *Conochitina lagenomorpha* Eisenack, p.85, pl.1, figs. 12-13.

cf. 1955a *Conochitina lagenomorpha* (Eisenack); Eisenack, pp. 160-161, pl.1, figs. 1-2.

cf. 1966a *Bursachitina lagenomorpha* (Eisenack); Taugourdeau, p.72.

cf. 1968 *Conochitina lagenomorpha* (Eisenack); Eisenack, p.164, pl.25, figs. 28-33.

cf. 1972a *Bursachitina lagenomorpha* (Eisenack); Eisenack, p.72.

cf. 1974 *Eisenackitina lagenomorpha* (Eisenack); Laufeld, pp.80-82, fig. 44.

cf. 1981 *Eisenackitina* sp. aff. *lagenomorpha* (Eisenack); Paris, pp. 158-159.

Remarks

Specimens of Eisenackitina cf. lagenomorpha do not possess the typical verrucate to granulate ornament of Eisenackitina lagenomorpha illustrated by Laufeld (1974, p.81): but display an ornament that is of low relief and micrognanulate. The most oral part of the vesicle is also not widened as in more typical specimens. Studied specimens do possess a rounded basal margin and a flat or slightly convex, or concave base as in E. lagenomorpha. When the operculum is present it is raised, slightly convex and possesses concentric growth lines.

Eisenackitina spongiosa sp. nov. and E. varireticulata sp. nov. both possess a reticulate ornament. E. oviformis (Eisenack, 1972) has a more ovoid vesicle.

Dimensions: Populations from the Wenlock type area, the Eastnor Park borehole and North Wales (in microns): length 72-164, width at basal margin 65-133, width of aperture 45-96. Number of specimens measured 15.

Material: 47 specimens.

Occurrence: Eisenackitina cf. lagenomorpha was recovered from the mid Coalbrookdale Formation of the Wenlock type area, the lower to mid Coalbrookdale Formation of the Eastnor Park borehole, and from the Denbigh Grits and Lower Nantglyn Flags Group of North Wales (Sheinwoodian to Homerian).

Laufeld (1974) recovered Eisenackitina lagenomorpha from the Ludlow of Gotland, and it has also been reported from Ludlow to Pridoli strata in Estonia (Eisenack 1955a, 1970; Kaljo 1970). There are several more papers that contain reports of the occurrence of this species from the early Caradoc to the Siegenian from several parts of the world; identification in these papers is probably faulty and they are therefore not included in synonymy.

Dorning (1981b) recorded Eisenackitina lagenomorpha as having a mid Ludlow to late Ludlow range in samples from the Wenlock type area. It is possible that the specimens of E. cf. lagenomorpha may be 'forerunners' to E. lagenomorpha *sensu stricto*.

Eisenackitina spongiosa Swire 1990

Pl.4, figs. 8-10; Pl.10, fig.8.

1990 *Eisenackitina spongiosa* Swire, pp.110-111, pl.1, figs. 8-10; pl.2, fig.8.

Derivation of name: from the Latin *spongiosus* meaning spongy or porous.

Holotype: MPK 5910. Pl.1, fig.10; MPA 26057, C3, G33/2. BGS Lower Hill Farm borehole, Shropshire (SO 5817 9788).

Diagnosis

A wide sub-conical to sub-cylindrical chitinozoan. The flexure, when present, is shallow and concave.. The base is flat to slightly convex and possesses an angular margin. The vesicle has two walls, an inner entire layer and an outer reticulate layer. The reticulate layer covers all of the vesicle and is joined to the inner wall by columns.

Description

Specimens possess a very dense reticulate ornament, which decreases in height orally. An operculum is sometimes present as a single disc.

Remarks

The short subcylindrical vesicle distinguishes *Eisenackitina spongiosa* Swire 1990 from the much longer conical vesicle of *Acanthochitina barbata* Eisenack, 1931; also whereas the reticulate ornament is entire on *E. spongiosa* sp. nov., on a single specimen of *A. barbata* there may be some spinose areas of ornament as well as a reticulate network. *A. barbata* also has a quite different stratigraphical range than *E. spongiosa* being widely reported from and restricted to the latest Caradoc and earliest Ashgill (see Grahn 1982; Jenkins & Legault 1979). *Pseudoclathrochitina carmenchui* (Cramer 1964) also possesses a perforate outer wall layer similar to *Eisenackitina spongiosa* but whereas *P. carmenchui* possesses only a 'perforate cingulum' *E. spongiosa* possesses a reticulate outer layer that covers the whole vesicle. *P. carmenchui* also possesses an 'oral mucron' whereas *E. spongiosa* does not (see also Cramer

1959, p.46). The recorded stratigraphical range of P. carmenchui is also different, it has been restricted to the Přídolían (Paris 1989, fig. 174).

Eisenackitina spongiosa Swire 1990 is placed in the genus Eisenackitina because of the subcylindrical vesicle shape, straight flanks, flat or convex base and the two-layered vesicle wall. The entire reticulate ornament over the vesicle surface of Eisenackitina spongiosa is denser than in E. varireticulata Swire 1990, and also distinguishes it from all other species of that genus. No chains have been found.

Dimensions: Populations from the Wenlock type area (in microns) length of vesicle 110-166 (holotype 130), maximum width of base 87-133 (holotype 101), width of aperture 51-85 (holotype 55). Number of specimens measured 30.

Material: 30 specimens.

Occurrence: Eisenackitina spongiosa was recovered from the Coalbrookdale Formation of the Lower Hill Farm borehole.

Eisenackitina varireticulata Swire 1990

Pl.4, figs. 1-3,6; Pl.10, figs. 4-7.

1990 Eisenackitina varireticulata Swire, p. 110, pl.1, figs. 1-3,6; pl.2, figs. 4-7.

Derivation of name: from the Latin *varietas* and *reticulatus*, meaning variously reticulate.

Holotype: MPK 5902. Pl.1, fig.1; MPA 26083, C4, P49/1. BGS Lower Hill Farm borehole, Shropshire (SO 5817 9788).

Diagnosis: A wide sub-cylindrical to sub-conical chitinozoan with straight flanks, no neck and no flexure. The base is generally flat but may be slightly concave or convex, it possesses an angular margin. The vesicle has two wall layers, the inner whole, the outer one forming a reticulate network which is joined to the inner by columns. The reticulate ornament is only present on the chamber, the oral tube being unornamented.

Description

In some specimens the ornament is damaged and is not clear; this effect could be preservational or may be due to damage during processing. The operculum when present, possesses a raised central 'boss'.

Remarks

The reticulate ornament of Eisenackitina varireticulata Swire 1990 is similar to that of Acanthochitina barbata Eisenack 1931; the latter differs, however in having a vesicle that is much longer and thinner, and an ornament that is entire. A. barbata also has a different recorded stratigraphical range being restricted to the latest Caradoc and earliest Ashgill. Pseudoclathrochitina carmenchui (Cramer 1964) differs from E. varireticulata in that the 'perforate' outer wall layer of the former is restricted to a cingulum, it also has an oral mucron which the latter does not possess (see also Cramer 1959, p.46). P. carmenchui has also only been recorded from the Přídolían (Paris 1989, fig. 174).

This species is placed in the genus Eisenackitina, because of the sub-cylindrical vesicle shape, straight flanks, flat or convex base, and double walled vesicle. The presence of a reticulate ornament clearly distinguishes it from other species of Eisenackitina, with the exception of Eisenackitina spongiosa sp.nov. which, however, possesses a reticulate ornament that is denser, and which covers the entire surface. No twins or chains were encountered.

Dimensions: Populations from the Wenlock type area (in microns) length of vesicle 85-135 (holotype 115), maximum width of base 66-145 (holotype 80), width of aperture 45-88 (holotype 55), maximum length of unornamented oral tube 27-52 (holotype 30). Number of specimens measured 40.

Material: 40 specimens.

Occurrence: Eisenackitina varireticulata was recovered from the Buildwas Formation of the Wenlock type area.

Eisenackitina sp. A

Pl.5, fig.1.

Description

A wide sub-cylindrical chitinozoan with broadly rounded flanks and base; the flexure is indistinct and shoulders are seldom observed. The vesicle thins orally and the neck possesses a collar. The vesicle surface is smooth to very finely granulate.

Remarks

The studied specimens are referred to *Eisenackitina* because of the subcylindrical vesicle; there is a similarity to *Eisenackitina* sp. C (Verniers 1982, p.44) which has the same vesicle shape and distinctive collar.

Dimensions: Populations from the Wenlock type area, Eastnor Park borehole, and North Wales (in microns), length 91-134, width of basal margin 60-114, width of aperture 38-76. Number of specimens measured 11.

Material: 112 specimens

Occurrence: *Eisenackitina* sp.A was recovered from the lower Buildwas to middle Coalbrookdale Formation of the Wenlock type area and the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole, it was sporadically found in the Denbigh Grits of North Wales.

The similar species *Eisenackitina* sp.C described by Verniers (1982) was recovered from middle Llandovery to early Wenlock strata of the Mehaigne area of Belgium.

Eisenackitina sp.B

Pl.5, figs. 2,3.

Description

A subcylindrical species of *Eisenackitina* with broadly rounded flanks, little or no flexure, no shoulder, and a flat to broadly rounded base. The vesicle surface is finely granulate; aborally there are a number of discrete spines with blunt to rounded tips; these spines are not present on the most oral part of the vesicle. The unornamented oral area is variable in size. An operculum is present on one of the studied specimens; this has a domed centre and attaches to a slightly flared edge of the aperture.

Remarks

The discrete spinose ornamentation on the aboral chamber of *Eisenackitina* sp.B distinguishes it from *E. varireticulata* Swire 1990, which possesses a similar ornament distribution but has a contrasting reticulate ornament. The spines also distinguish it from any other described species of *Eisenackitina*.

Dimensions: Populations from the Lower Hill Farm borehole (in microns): length 140-152, width at basal margin 85-93, width of aperture 65-72, maximum length of unornamented oral area 33-78, maximum length of spines 7. Number of specimens measured 4.

Material: 4 specimens.

Occurrence: *Eisenackitina* sp.B was recovered from the Coalbrookdale Formation (Sheinwoodian) of the Lower Hill Farm borehole.

Genus *Gotlandochitina* Laufeld 1974

Type Species: by original description *Gotlandochitina martinssoni* Laufeld 1974.

Diagnosis: Refer to Laufeld 1974, p.83.

Remarks: It is possible when a lot of spines are present to confuse species of Gotlandochitina with those of Angochitina Eisenack 1931; distinct rows of spines which may coalesce and interconnect have to be observed in order to place a specimen in Gotlandochitina, remaining similar species are placed in Angochitina.

Gotlandochitina martinssoni Laufeld 1974

Pl.9, figs. 1,3.

1974 Gotlandochitina martinssoni Laufeld, pp. 86-89, fig. 49.

Remarks

Studied specimens of Gotlandochitina martinssoni possess a cylindro-ovoidal vesicle. The neck comprises about half the length of the vesicle and has a slightly widened oral most edge. The typically smooth vesicle wall possesses a number of long and curved spines which are arranged in longitudinal rows; observed specimens possess fewer spines than specimens illustrated by Laufeld (1974, p.88, fig.49). Spines are occasionally coalescent and may branch simply and there is a decrease in their length towards the aperture.

Gotlandochitina spinosa (Eisenack 1932) differs from G. martinssoni in that in the former the spines are longer, thicker and branch more profusely. It is probable that specimens figured by Eisenack (1964a, pl.28) referred to Sphaerochitina sp. aff. spinipes and Sphaerochitina spinipes from lower Wenlock strata of Gotland belong to G. martinssoni.

Dimensions: Populations from the Lower Hill Farm borehole (in microns): length 130-146, width at basal margin 59-70, width of aperture 29-39, maximum length of spine 23. Number of specimens measured 11.

Material: 11 specimens.

Occurrence: Gotlandochitina martinssoni was recovered from the Coalbrookdale Formation (Sheinwoodian) of the Lower Hill Farm borehole. G. martinssoni has been recorded from lower Wenlock strata of Gotland where it has a restricted stratigraphical range (Laufeld 1974); Dorning (1981b) has previously recovered it from the lower Coalbrookdale Formation of the Wenlock type area. Although morphologically distinctive G. martinssoni is a relatively rare chitinozoan constituting only up to 5% of a chitinozoan assemblage at its most numerous.

Gotlandochitina spinosa (Eisenack 1932)

Pl.5, fig.5.

1932 Conochitina spinosa Eisenack, pp. 271-272, pl.12, figs.11-13

1959a Ancyrochitina spinosa (Eisenack); Eisenack, pp. 13-14, fig. 26, pl.2, figs 1-2.

1964a Ancyrochitina spinosa (Eisenack); Eisenack, p. 325, pl.28, figs. 10-11.

1974 Gotlandochitina spinosa (Eisenack); Laufeld, p.91, fig.52.

Remarks

The spines of Gotlandochitina spinosa are characteristically long thick and distally branching. On some of the studied specimens some of the spines display coalescent bases which are elongated in a longitudinal direction. The vesicle wall of G. spinosa is smooth and the base of the vesicle broadly convex. The most oral part of the neck is typically widened, a feature not mentioned by Laufeld (1974) in the emended diagnosis; a possible reason is that specimens he illustrated appear to possess damaged necks (Laufeld 1974, fig.52).

Dimensions: Populations from the Lower Hill Farm borehole (in microns): length 105-120, width at basal margin 65-74, width of aperture 30-37, maximum length of spines 20. Number of specimens measured 3.

Material: 3 specimens.

Occurrence: *Gotlandochitina spinosa* was recovered from the mid Coalbrookdale Formation (Sheinwoodian) of the Lower Hill Farm borehole. It is a rare species and was found in only one sample.

Gotlandochitina spinosa was erected on material extracted from an erratic boulder of crinoidal limestone of Silurian age (Eisenack 1932). Eisenack designated a neotype from the middle Venlockian of Gotland (Eisenack 1964a), where *G. spinosa* is restricted to rocks of this age (Laufeld 1974). It has previously been reported from the middle Devonian (Givetian) of Iowa, USA (Dunn 1959); from upper Devonian strata in Morocco (Grigani & Mantovani 1964); from lower Silurian and lower Devonian strata in Brazil (Da Costa 1966); and from strata of Wenlock age in NW Spain (Cramer 1964).

Gotlandochitina spinosa has not previously been recorded from the type Venlock area.

Genus *Linochitina* Eisenack 1968

Type Species: by original designation *Conochitina erratica* Eisenack 1931.

Diagnosis: Refer to Eisenack 1968a, p.170.

Linochitina cf. *erratica* (Eisenack 1931)

Pl.5, figs.4,7.

cf. 1931 *Desmochitina erratica* Eisenack, p.92, pl.3, figs. 6-8.

cf. 1962a *Desmochitina erratica* Eisenack; Eisenack, p.307, pl. 17, figs. 10-11.

cf. 1966a <u>Eremochitina</u> ? <u>erratica</u> (Eisenack); Taugourdeau, p.38.

cf. 1968a <u>Linochitina erratica</u> (Eisenack); Eisenack, p.170, pl.31, fig.17.

cf. 1974 <u>Linochitina erratica</u> (Eisenack); Laufeld, pp. 99-100, fig.59.

<u>Remarks</u>
A slender species with gently curved flanks and an inconspicous flexure and shoulder. The basal margin is bluntly to broadly rounded and is provided with a short, thickened narrow edging. Unlike typical specimens of <u>L. erratica</u> there is no distinct basal process and the vesicle wall is not smooth. The British specimens possess a low relief microgranulate ornament. Twins and chains are uncommon.

<u>Linochitina</u> cf. <u>erratica</u> has affinities with <u>L. klonkensis</u> Paris & Laufeld 1980, the latter being differentiated by an oral constriction in the vesicle, and by the possession of a collar. Also whereas <u>L. erratica</u> possesses an aboral border <u>L. klonkensis</u> does not.

<u>Dimensions</u>: Populations from the Lower Hill Farm borehole, and North Wales (in microns): length 121-130, width at basal margin 48-55, width of aperture 38-43. Number of specimens measured 10.

<u>Material</u>: 141 specimens.

<u>Occurrence</u>: <u>Linochitina</u> cf. <u>erratica</u> was recovered from the mid Buildwas to lower Coalbrookdale Formation (Sheinwoodian) of the Wenlock type area, and from the Denbigh Grits (Sheinwoodian) of North Wales.

<u>Linochitina erratica</u> has a recorded range of middle Wenlock to early Ludlow in Gotland (Eisenack 1964a, Laufeld 1974). It has been recorded from lower Wenlock strata in Estonia (Kaljo 1970), and from middle to upper Llandovery strata in Morocco (Correia 1964). Dorning (1981b) recorded specimens which he referred to <u>L. erratica</u> from the middle Wenlock (Coalbrookdale Formation) to the middle Ludlow (Bringewood Beds) of the Wenlock type area, it is not possible to compare them to observed specimens because I have not seen them.

Genus _Margachitina_ Eisenack 1968

Type Species: by original designation _Desmochitina margachitina_ Eisenack 1937.

Diagnosis: Refer to Eisenack 1968a, p.182.

Remarks

Margachitina is characterised by its discoid chamber and orally flaring copula with large terminal disc. It is commonly found in chains.

Margachitina cf. _catenaria_ subsp. _crassipes_ Paris 1981

Pl.5, figs.6,8.

cf. 1969 _Margachitina margaritana_ (Eisenack); Goldstein & Andress, pl.2, fig.4.

cf. 1973 _Margachitina margaritana poculum_ (Collinson & Schwalb); Obut, pl.16, fig.1,2.

cf.?1973 _Margachitina margaritana_ (Eisenack); Cramer, pl.2, fig.20,21,24.

cf. 1981 _Margachitina catenaria_ subsp. _crassipes_ Paris, pl.25, fig. 13-16.

Remarks

One of the characteristic features of this sub-species of _Margachitina_ is the ornament, which Paris (1981, p.143) in the original diagnosis describes as 'annular thickenings up to twelve in number'. Other described diagnostic features are the vesicle which is 'sub-lozenge' shaped having a 'maximum diameter half way up the vesicle' and possessing a short thick cylindrical peduncle (copula) and 'conical operculum which is surrounded by a thin flange'.

Specimens studied possess a similar ornament to that described by Paris (1981) but with additional ridges running longitudinally (orally-aborally) down the length of the vesicle. The conical operculum is circular and unornamented; a thin surrounding fringe referred to by Paris (1981) was not observed. The copula was characteristically cylindrical and short, although it was bent over without apparent tearing in some of the studied specimens and could not have been too thick.

Dimensions: Populations from the Lower Hill Farm borehole (in microns): length 80-92, maximum width of vesicle 72-79, maximum length of peduncle 9-13. Number of specimens measured 5.

Material: 5 specimens.

Occurrence: *Margachitina* cf. *catenaria* subsp. *crassipes* was recovered from the mid Coalbrookdale Formation (Sheinwoodian) of the Lower Hill Farm borehole.

Previously typical specimens of the subspecies have been recovered from the Přídolí of France (Paris 1981), and of Podolia (USSR) (Obut 1973); with comparable specimens illustrated by Cramer (1973) in material from the middle and upper Silurian of the Florida subsurface.

Margachitina margaritana (Eisenack 1937)

Pl.6, figs.1,2,4; Pl.9, figs.7,9.

1937 *Desmochitina margaritana* Eisenack, p.221, pl.15, figs.9-11.

1963 *Desmochitina margaritana* Eisenack; Kozlowski, pp.434-435, fig.7.

1968a *Margachitina margaritana* (Eisenack); Eisenack, p.182, pl.24, figs. 17-18.

1971 *Margachitina margaritana* (Eisenack); Laufeld, p.296, pl.2: N.

1973 *Margachitina margaritana* (Eisenack); Obut, pl. 15, figs. 12-13.

1974 Margachitina margaritana (Eisenack); Laufeld, p.102, fig.62.

1978 Margachitina margaritana (Eisenack); Verniers & Rickards, pl.2, fig.15.

1981 Margachitina margaritana (Eisenack); Verniers, pl.2, fig.31.

1982 Margachitina margaritana (Eisenack); Verniers, p.47, pl.9, figs. 227-229.

Remarks

Margachitina margaritana is very commonly found in twins or chains, probably because the connection between vesicles is very strong. The strength of this attachment is illustrated by the fact that when a chain is subjected to strain the copula tends to break at its thinnest part before the attachment between the flared part of the copula and the apertural embayment of the next vesicle breaks. The vesicle surface is typically unornamented and smooth.

Margachitina catenaria Obut 1973 possesses an ornamented vesicle.

Dimensions: Populations from the Wenlock type area, Eastnor Park borehole and North Wales (in microns): length 85-105, width at basal margin 65-77, width of aperture 42-55. Number of specimens measured 13.

Material: 199 specimens.

Occurrence: Margachitina margaritana was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area; the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole, and the Denbigh Grits and Lower Nantglyn Flags of North Wales (Sheinwoodian to Homerian).

In Gotland Margachitina margaritana has been recovered from uppermost Llandovery to upper Wenlock strata (Eisenack, 1962a, 1962b, 1964; Taugourdeau & De Jekhowsky, 1964; Laufeld, 1971, 1974). In Sweden it is known from the late Wenlock (Laufeld et al. 1975); in Estonia and in Podolia it occurs in the lower Wenlock (Kaljo 1970; Laufeld 1971). M. margaritana has also been found in strata of similar age from the Algerian Sahara

(Taugoudeau & De Jekhowsky, 1960), in the Silurian subsurface of Florida (Goldstein et al., 1969; Cramer, 1973), in Brazil (Lange, 1967a; Da Costa 1967, 1971a), in Nova Scotia, Canada (Cramer 1970), and in Belgium (Verniers 1982). It has a previously recorded range in the Venlock type area of late Llandovery to early Wenlock (Dorning 1981b). Its range is extended here to at least mid Wenlock.

Following the strict definition of Margachitina margaritana given by Eisenack (1968) and Laufeld (1974), this species is a good index fossil with a range from the latest Llandovery to the middle of the Wenlock.

Genus Salopochitina Swire 1990

Derivation of name: *Salopia*, Roman name for the area that is now called Shropshire.

Type Species: by original description Salopochitina bella Swire 1990.

Diagnosis: Chitinozoans with little or no flexure and short neck. The aperture is widened and possesses a collar. The base is broadly rounded. Attached to the centre of the base, or to the basal margin, are one to three elongated appendices which are up to twice as long as the vesicle.

Remarks: The outline of the vesicle is superficially similar to that of Ancyrochitina Eisenack 1955b, but is shorter and more comapact. The vesicle also possesses a collar, a feature that is not associated with species of Ancyrochitina. The basal margin of Ancyrochitina is provided with appendices which are short and sometimes branch. In Salopochitina the attachment of the appendices is either to the centre of the base, or to the basal margin, and the appendices are much longer and do not branch.

Plectochitina Cramer 1964 differs from Salopochitina in having appendices that are distally connected, anastomosing and partly spongy; no connection of the appendices has been noted in Salopochitina and the appendices are solid for their entire length. Plectochitina also possesses a longer neck and deeper flexure than Salopochitina.

Salopochitina bella Swire 1990

Pl.4, figs.4,5,7; fig. 7; Pl.10, figs.1-3.

1990 *Salopochitina bella* Swire, p.109, pl.1, figs. 4,5,7; pl.2, figs. 1-3.

Derivation of name: *bella*, Latin adjective for beautiful.

Holotype: MPK 5913. Pl.2, fig.3; MPA 26083, C2, P50/2. BGS Lower Hill Farm borehole, Shropshire (SO 5817 9788).

Diagnosis: The vesicle is subconical to ovoid with a broadly rounded base. The flexure, when present, is shallow and concave. The short neck widens orally and possesses a collar. There are one to three solid elongated appendices attached to the centre of the base or the basal margin of the vesicle; these appendices are up to twice as long as the vesicle and are widest they join the base. The vesicle is unornamented.

Description: The appendices are not branched, and apart from broadening proximally to their connection to the vesicle, are of equal width for their entire length. Distal terminations of the appendices are generally blunt and rounded. When one appendix only is present, it is attached to the centre of the base; when two or three are present, they are attached to the basal margin of the vesicle. The appendices may possess a rugose ornament.

Remarks: The differing number of appendices can be accounted for by intraspecific variation; this is indicated by a morphotype (Pl.2, fig.1) that possesses one incipient appendix and two longer appendices. A similar stratigraphical occurrence for all the different types supports this idea.

Similar species are *Ancyrochitina longicornis* and *Ancyrochitina nodosa* Taugourdeau & De Jekhowsky 1960. *Ancyrochitina longicornis* has one long appendix attached to the centre of the vesicle, and *A. nodosa* has three which are attached to the basal margin. In both species the appendices are also of the same width for their entire length. The taxa differ from *Salopochitina* in the shape of the vesicle which in *S. bella* Swire 1990 is sub-conical and in *A. longicornis* and *A. nodosa* is cylindro-spherical. A further difference is that in A. longicornis and A. nodosa the appendices are hollow, whereas in S. bella they are solid.

Salopochitina bella Swire 1990 bears a resemblance to Conochitina filifera *sensu* Jardiné & Yapaudjian 1968 (Pl. 6, fig.s 1,2) and to Conochitina ? monterrosae Cramer 1969a. As Jardiné and Yapaudjian do not describe their specimens it is not possible to ascertain synonymy. Cramer 1969a (p. 491) refers to a 'digitate keel' and 'reduced three to four, apparently quite fragile appendices', as Iam unsure what is being referred to by a 'digitate keel' and studied specimens possessed sometimes only one appendix, Conochitina ? monterrosae is not presently included in synonymy. The study of Jardiné & Yapaudjian's and Cramer's specimens will undoubtedly sort out the taxonomic hierarchy.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): length of vesicle 80-140 (holotype 130), maximum width of base 55-90 (holotype 72), width of aperture 30-53 (holotype 44), maximum length of appendix 30-250 (holotype 190). Number of specimens measured 110.

Material: 110 specimens.

Occurrence: Salopochitina bella Swire 1990 was recovered from the Buildwas Formation of the Wenlock type area and the Woolhope Limestone of the Eastnor Park borehole. Similar forms have also been recorded from the Wenlockian of Libya (Gordon Wood, Written. Comm.).

Cramer 1969a recorded Conochitina ? monterrosae from probable early Wenlockian sediments in the USA. Jardiné & Yapaudjian 1968 recorded Conochitina filifera from sediments of Wenlockian or early Ludlovian age in the Algerian Sahara.

Genus Sphaerochitina Eisenack 1955a

Type Species: by original designation Lagenochitina sphaerocephala Eisenack 1932.

Diagnosis: Refer to Eisenack 1955a, p. 162.

Remarks: Using the original diagnosis of the genus (Eisenack 1955a, p.162.) Sphaerochitina is restricted to those specimens with a spherical chamber, cylindrical neck, and a low ornament of small spines or tubercles.

Sphaerochitina aff. sphaerocephala (Eisenack 1932)

Pl.9, figs.2,5,6,8.

aff. 1932 Lagenochitina sphaerocephala Eisenack, pp. 271-272, pl.12, fig. 14-15.

aff. 1955a Sphaerochitina sphaerocephala (Eisenack); Eisenack, p.162, pl.1, figs. 5-6.

aff. 1964a Sphaerochitina sphaerocephala (Eisenack): Eisenack, p.321, pl.30, fig.5.

aff. 1968a Sphaerochitina sphaerocephala (Eisenack): Eisenack, p.175, pl.28, figs. 14-22, pl.29:33, pl. 34:20.

aff. 1970 Sphaerochitina sphaerocephala (Eisenack): Eisenack, p.306, fig. 1:R, non 1: E,F.

aff. 1974 Sphaerochitina sphaerocephala (Eisenack): Laufeld, p.112, fig.69.

aff. 1980 Sphaerochitina sphaerocephala (Eisenack): Paris, Laufeld & Chlupáč, pl.2, figs. 10,14,16; pl.3, fig.3.

aff. 1981 Sphaerochitina sphaerocephala (Eisenack): Paris, pl.22, figs. 9-11,14,16,18-20; pl.23, figs.9,12,13,15,18,19; pl.26, fig.11.

Remarks

Typical specimens of Sphaerochitina sphaerocephala possess a cylindro-spheroidal vesicle with a neck that is gently widened in an oral direction and flares abruptly at the aperture. Chamber shape varied in the studied specimens from spheroidal to almost square with most of the observed specimens possessing the typical elongated neck and widened aperture. This variation of vesicle shape is probably due to differences in compression. The granulate ornament covering the vesicle surface of typical specimens of S. sphaerocephala is not apparent, although in a number of specimens small aboral spines are present at the base of the neck.

Eisenack (1972a) discusses at length the variability which he observed in the population of Sphaerochitina sphaerocephala: from his study he intended to show a series of morphological changes with time. Some of the specimens he illustrates though, are not characteristic forms. Laufeld (1974) stated that 'S. sphaerocephala has been reported extensively in the literature and it is hard to escape the conclusion that it has become a waste-basket taxon'.

Paris (1981, pp. 273-274) disagress and suggests the use of statistical techniques to separate out a typical species and intermediate forms, taking into account modification of the outline as well as ornamentation type and distribution.

The problem with the studied specimens was preservational. All were recovered from 'basinal' samples in which the thermal alteration index was high and therefore all the specimens were 'brittle' and damaged in some way; it proved impossible to apply statistical techniques on overall shape to split the population, and therefore in the present study at least, it is difficult to ignore Laufeld's conclusions.

Dimensions: Populations from North Wales and Central Wales (in microns): length 130-138, width at basal margin 65-73, width of aperture 32-42. Number of specimens measured 10.

Material: 33 specimens.

Occurrence: *Sphaerochitina* aff. *sphaerocephala* was recovered from the Nant-ysgollon Shales of central Wales, and the Denbigh Grits of North Wales. *Sphaerochitina sphaerocephala* has previously been recovered from the early to mid Ludlow of Gotland (Laufeld 1974), and from the Přídolí of Estonia (Eisenack 1970) and Bohemia (Paris *et al*. 1981). Dorning (1981a) recovered it from the upper Ludlow of the Welsh Borderlands.

7.4. Group Acritarcha Evitt 1963

The name 'acritarch' (formally the Group Acritarcha) was suggested by Evitt (1963) to cover part of the microfossils known previously as the 'hystrichospheres' (Family Hystrichosphaeridae Wetzel 1933). In 1963 (p.44) Downie, Evitt and Sarjeant defined the group as:

"Unicellular or apparently unicellular microfossils consisting of a test composed of organic substances and enclosing a central cavity". The shape of the test is very variable and the "shell opens by a rupture, splitting, or formation of a simple circular pylome. Rarely tests are loosely associated in a chain".

It is thought that the acritarchs are a polyphyletic group of planktonic marine microfossils of diverse relationships (Downie 1973; Tappan 1980). Many show little resemblance to any extant group, with most too simple to be confidently allocated anywhere (Downie 1984, p.2).

A number of subdivisions of the group acritarch on a supra-generic level have been suggested (Wetzel 1933; Eisenack 1954; Downie et al. 1963 ; Mädler 1963; Timofeev 1966; Jux 1975; Al-Ameri 1986). The various subdivisions have mainly been based on wall structure and excystment mechanisms, but also to a lesser extent on clustering.

In the sub-groups created by Downie et al. (1963) the symmetry and shape of the body of the acritarch was given greatest weight. These are characters that are always readily visible, and although of little significance in establishing the natural affinities of the acritarchs they form the basis of an easily used classification, which is followed in this thesis. A summary of the different subgroups is set out below and their main features illustrated in Fig. 47:

1. Sphaeromorphs (more or less spherical smooth forms).

2. Acanthomorphs and Polygonomorphs (round and more or less polygonal forms bearing spines).

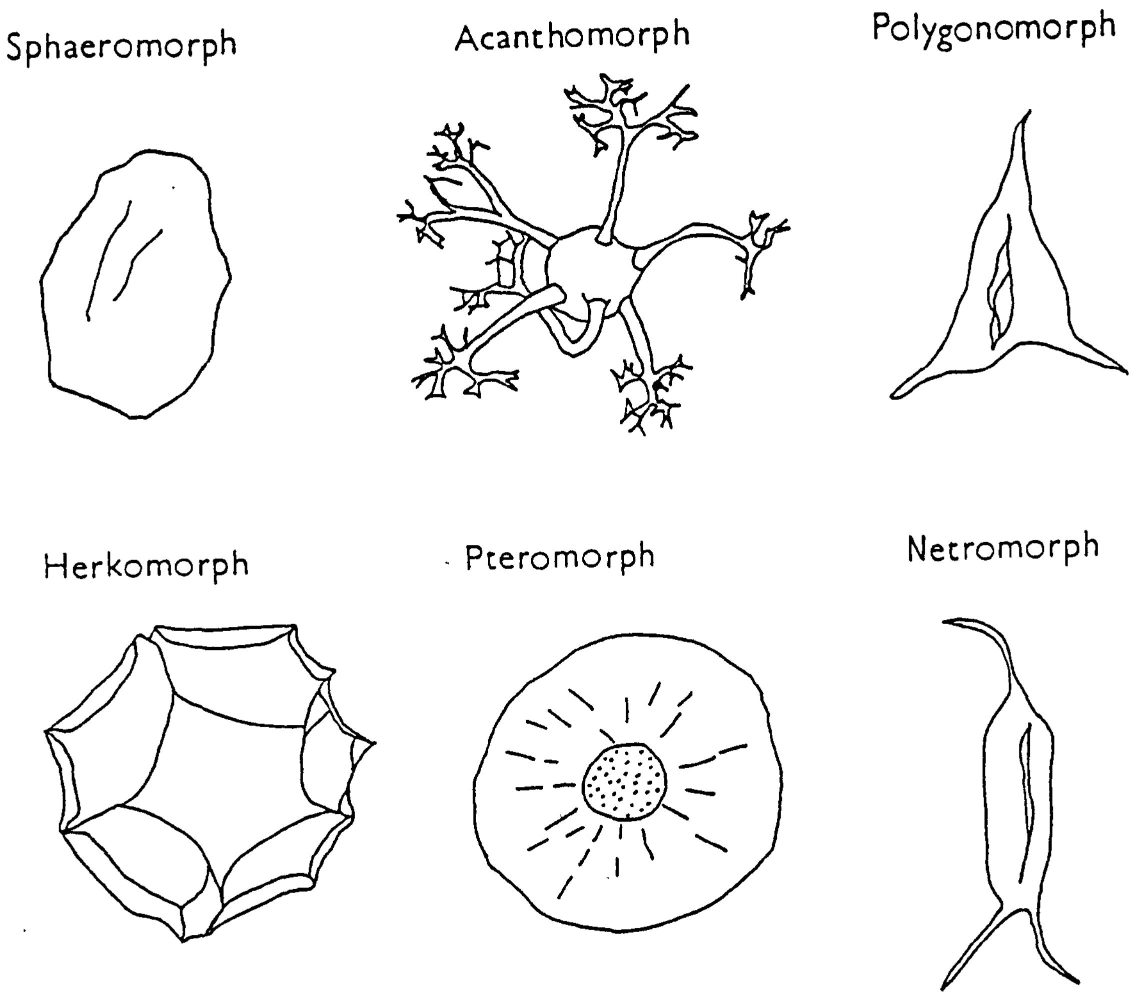


Fig. 47 . The acritarch subgroups, after Downie et al. 1963.

3. Pteromorphs and Herkomorphs (round forms bearing raised veils, crests or alae).

4. Diacromorphs, Netromorphs and Oomorphs (round or elongate bodies with polar differentiation).

7.4.a. Glossary of used descriptive terms for the acritarchs

Glossaries of morphological terminology have been published and used in the systematic descriptions of the acritarchs: see glossaries provided by Kjellström (1971, p. 9-13), Lister (1970, p. 24-26), Eisenack *et al*. (1973, p. 9-18), and Williams *et al.* (1973). Some ambiguity, however exists in the application of certain terms and because of this a glossary of terms used in this thesis is set out below. Figs. 48,49 and 50 illustrate respectively different ornament types, different process types and different excystment types encountered in this study.

Bacculate. with a sculpture of bacculate elements, club like. Synonym: pilate.

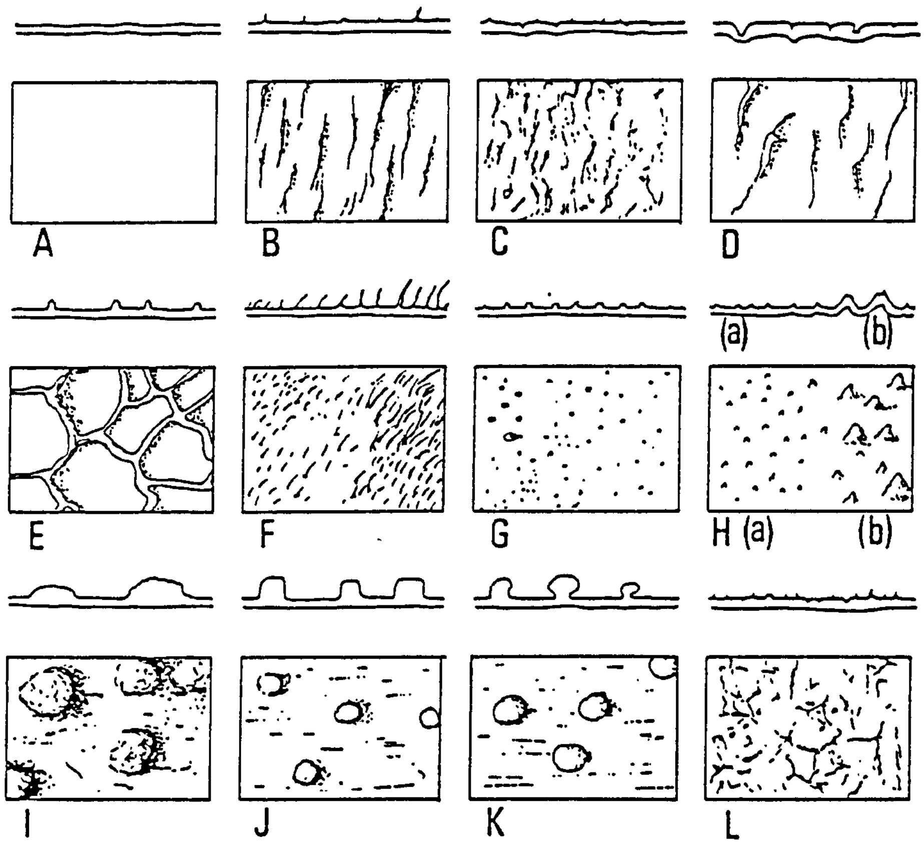
Bifurcate process. process distally split into two tips. Synonym: forked process.

Body. synonym of vesicle (see below), used for example by Downie 1963, p.635.

Camerate. that condition of a cyst in which a cavity separates the inner from the outer vesicle wall.

Capitate. (synonymous with claviform) applied to processes which are dilated at their distal extremities.

Claviform. see capitate.



A: psilate
B: rugulate
C: scabrate
D: striate
E: reticulate
F: filose or ciliate

G: granulate
H: denticulate (a) or echinate (b)
I: verrucate
J: bacculate or pilate
K: clavate
L: shagrinate

Fig.48 . Acritarch ornaments (after Eisenack et al. 1973).

Cauliflorate. applied to processes which divide into a number of bud-like extensions at their distal extremities (e.g. in the genus *Cymbosphaeridium* Lister 1970).

Central body. synonym of vesicle (see below), used for example by Cramer 1964.

Crest. a raised flange which interconnects in the Herkomorphs to form a polygonal pattern of fields (e.g. *Cymatiosphaera* Wetzel 1933, emend. Deflandre 1954).

Cryptosuture. suture possessing no visible surface manifestation on the cyst. Position of a cryptosuture only becomes evident when dehiscence has commenced.

Cyclopyle. see pylome.

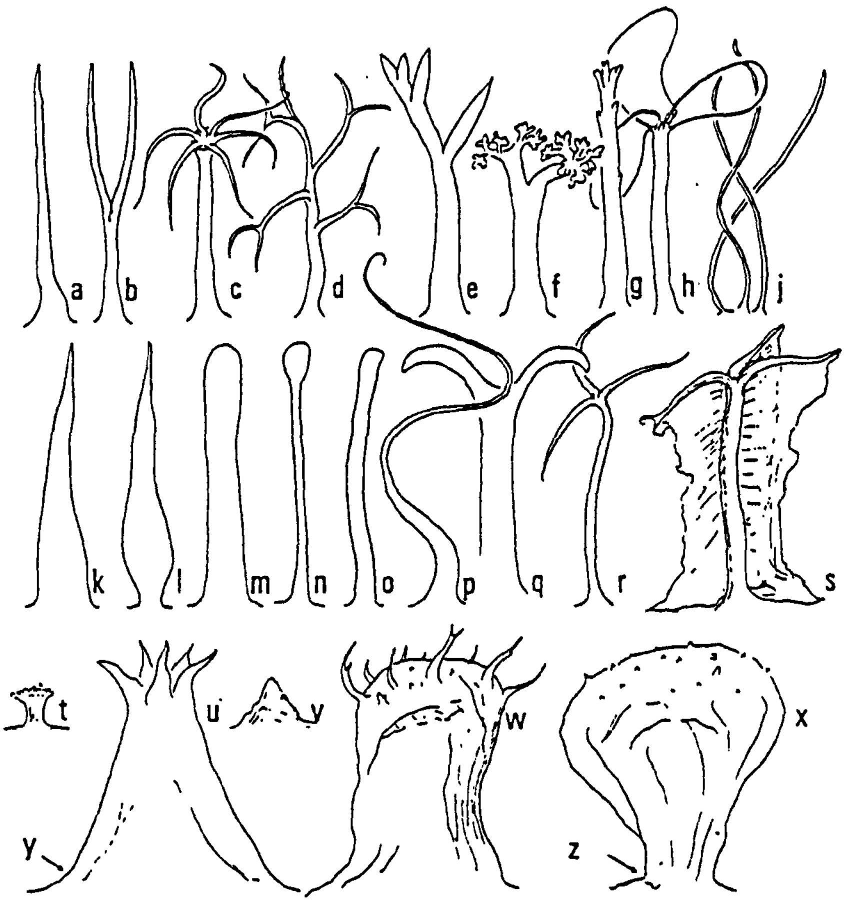
Cyst. the spore or resting stage of a unicellular algal organism; cyst nature is indicated by the presence of an excystment suture.

Dehiscence. used specifically to express the phenomena of 'opening' or 'parting' along a suture.

Dichotomous. used to indicate a forking of a process into two roughly equivalent pinnae.

Echinate. wall with spiny or cone like sculptural projections; see Kjellström (1971, Fig.4).

Epityche. This term was introduced by Loeblich & Tappan (1969) for the excystment structure formade by a curving split allowing a flap to open. A number of variants have been subsequently noted. For instance Cramer (1970) distinguished C-shaped and S-shaped splits in *Veryhachium* Deunff ex. Downie 1959.



a: simple process
b: bifurcated process
c: palmate process
d: branching process
e: process with daggerlike pinnae
f: cauliflorate or lobulate branching
g: manate or digitate branching
h: palmate branching with loops
j: filose or filiform processes
k: acuminate process
l: basal constriction
m: cylindrical process
n: capitate process
(bulbous or clavate termination)
o: evexate or truncated process
p: whiplike or flagelliform process
(as in Aremoricanium rigaudae)
q: equifurcate or dichotomous process
r: trichotomous (/ly palmate) process
s: petaloid process
(arrow: peteinos or veil structure)
t: Tuberkel (as in Baltisphaeridium nanninum)
u: conical (palmate) process
v: piquant
w: cylindrical process
x: clavate process
y: carved process contact
z: constriction

a-s, w, z: angular process contact or square process base.

Fig. 49. Acritarch process types (after Eisenack et al. 1973).

Epibystra. This term was introduced by Playford (1977, p.9)) for an excystment structure formed by the split of the cup of one end of the pulvenoid processes into a zigzag line of opening, e.g. the genus *Pulvinosphaeridium* Eisenack 1954 emend. Deunff 1954.

Equifurcate. homomorphic branching in which two or more branches arise from the distal extremity of a process. The branches arise from a single node and are more or less equal in length.

Excystment suture. the principal suture in the epicyst, controlling the excystment opening.

Filose. with filiform processes (a sculpture of thin hair-like elements)

Foveolate. an ornament of small discrete pores on a vesicle surface.

Granulate. a sculpture type consisiting of tiny warts, flat crested denticules and other elements which are essentially equidimensional and 1μ or less in height and diameter.

Heteromorphic processes. these constitute, on the same vesicle, two discrete morphological process orders (e.g. furcate and simple processes), e.g. *Visbysphaera* Lister 1970, also see Kjellström (1971, p.12).

Homomorphic. these constitute a single morphological process order occurring on a given vesicle (e.g. furcate or simple processes); after Kjellstrom (1971, p.12).

Inner body. in two-layered acritarchs, the inner-wall plus the vesicle cavity.

Inner wall. in two-layered acritarchs, the wall lining the vesicle cavity.

Laevigate. smooth.

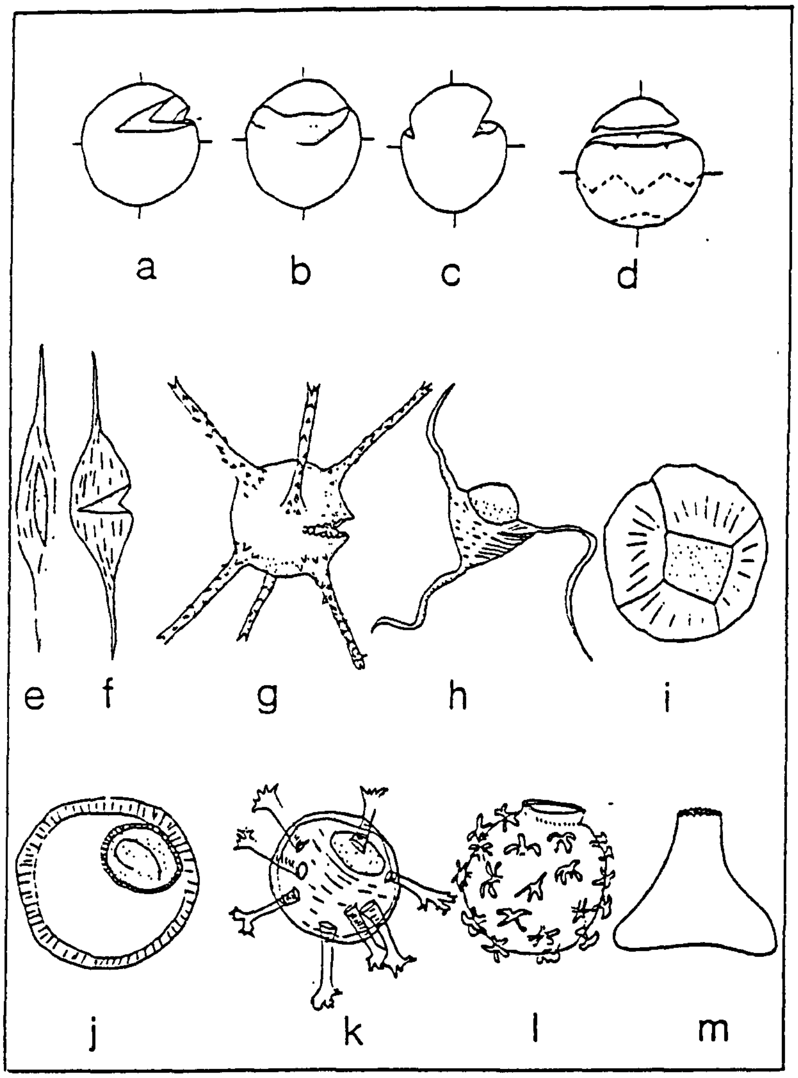


Fig.50. Excystment apertural openings in acritarchs: a-d, Epityche; a, lateral view; b, dorsal view; c, ventral view; d, opening by obvious suture; e-g, Median split; e, lateral split; f, equatorial split; g and m, zigzag face; h, Epityche; i, pseudo-archaeopyla; j-l, Cyclopyle; j; in thick wall; l, with collar; m, epibystra (after Al-Ameri 1986).

Median Split. excystment suture situated roughly equatorially. A few forms excyst by splitting into two equal halves (e.g. in the genera Orthosphaeridium Eisenack 1968b emend. Kjellström 1971 and Leiofusa Eisenack 1938), while some cysts develop a central equatorial split (e.g. in the genera Helosphaeridium Lister 1970 and Oppilatala Loeblich & Wicander 1976).

Multifurcate. processes that branch many times.

Outer wall. in two layered acritarchs, the wall not in contact with the vesicle cavity; it may be in close contact (appressed) or separated from the inner wall (see above).

Palmate. distal process branching that looks similar to a hand.

Plug. darkened area in process-central body union, probably formed by the separation of ectodermal matter at the inside of the proximal part of the process cavity.

Proximal. applied to that part of a process or ornament nearest to its origin on the vesicle.

Psilate. synonym of laevigate.

Pylome. (synonymous with cyclopyle, Eisenack 1969b) an excystment opening which is circular, resulting from the removal of a circular operculum; as used by Lister 1970.

Reticulate. like a net or network.

Rugulate. surface irregular.

Scabrate. surface texture of outer wall resulting from the presence of numerous closely spaced linear markings about 2μ in length.

Simple process. non-furcate distally terminated process.

Tubercles. in reference to an ornament of nodes or 'lumps' on the vesicle surface.

Vesicle. the 'central body', i.e. the cyst minus the processes, veils crests, etc. The term may be used to include or not include the operculum.

Vesicle cavity. space enclosed by vesicle wall.

Subgroup Sphaeromorphitae Downie, Evitt & Sarjeant 1963

Genus Alveosphaera Kirjanov 1978

Type Species: by original designation Alveosphaera locellata Kirjanov 1978.

Diagnosis: Kirjanov 1978, p.23.

Remarks: Specimens of Alveosphaera are characterized by the thick double walled subspherical vesicle and an ornament of small pores or hexagonal cells.

Alveosphaera cf. coarctata Kirjanov 1978

(Pl. 26, fig. 6)

cf. 1978 Alveosphaera coarctata Kirjanov, p.24, pl. VII, figs. 1,4.

Remarks

The observed specimens possess large spherical to subspherical double-walled vesicles, which are ornamented with a reticulate network of hexagonal cells. The outer vesicle wall is thick and has a waxy appearence.

Observed specimens bear a resemblance to Alveosphaera coarcta Kirjanov 1978 which although smaller possesses the same reticulate vesicle and thick wall. Alveosphaera alveolata Kirjanov 1978 and Alveosphaera ? deflandrei (Stockmans & Willière) Priewalder 1987 are both smaller. Alveosphaera cf. coarctata bears a superficial resemblance to some species of Tasminites but the former does not possess the canals which pass through the thick outer wall of the latter.

Dimensions: Populations from the Venlock type area (in microns): vesicle diameter 90-110, width of hexagonal cell 2-3. Number of specimens measured 6.

Material: 6 specimens

Occurrence: *Alveosphaera* cf. *coarctata* was recovered from the Coalbrookdale Formation of the Venlock type area (Sheinwoodian to Homerian). Kirjanov (1978) recovered *Alveosphaera coarctata* from the upper Silurian of Podolia and the Ukraine.

Alveosphaera ? *deflandrei* (Stockmans & Willière 1963) Priewalder 1987

(Pl. 11, figs. 1-4)

1963 *Leiosphaeridia deflandrei* Stockmans & Willière, p. 474, pl.1, figs. 2,3.

1979 *Leiosphaeridia deflandrei* Stockmans & Willière; Eisenack *et al*. p. 289.

1987 *Alveosphaera* ? *deflandrei* (Stockmans & Willière); Priewalder, p. 23, pl.1, figs. 4,5.

Remarks

Observed specimens typically possess a vesicle wall that is peforated by small pores, the interporate areas form a fine reticulum. Although no reference is made to an excystment mechanism in the original diagnosis, the illustrated specimens appear to have excysted (Stockmans & Willière 1963, pl.1, figs. 2,3) and observed specimens did excyst by means of a median split. Specimens more typical of *Alveosphaera* possess a thicker vesicle wall.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): width of vesicle 22-28, size of pores approximately 0.5-1. Number of specimens measured 10.

Material: 57 specimens.

Occurrence: *Alveosphaera* ? *deflandrei* was recovered from the Buildwas and lower Coalbrookdale Formation of the Wenlock type area, and the upper Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole (Sheinwoodian).

Previously *Alveosphaera* ? *deflandrei* has been recorded from the upper Llandovery of Belgium (Stockmans & Willière 1963) and Austria (Priewalder 1987). Barron (1989) records *Alveosphaera* spp. from the mid-Wenlock of the Cheviot Hills of NE England but unfortunately neither describes nor illustrates them.

Alveosphaera ? *densiporata* Priewalder 1987

(Pl. 11, figs. 5-7)

1987 *Alveosphaera* ? *densisporata* Priewalder, pp. 23,24, pl.1, figs. 6-9; pl. 17, figs. 3,4.

Remarks

Alveosphaera ? *densisporata* is a large thin-walled species with dense pores on the vesicle surface (Priewalder 1987, p. 23); these features distinguish it from *A.*? *deflandrei* (Stockmans & Willière) Priewalder 1987 which is smaller, and from *A. coarctata* Kirjanov 1978, which has larger pores and a thicker vesicle wall.

In studied specimens the thin vesicle wall and large size has led to folding, so that a typical vesicle is' cigar' shaped. The assignment of observed specimens to the genus *Alveosphaera* is questionable because of the thin wall, more typical specimens of *Alveosphaera* possess a much thicker vesicle wall.

Dimensions: Populations from the Wenlock type area (in microns): width of vesicle 37-70, size of pore approximately 1-2. Number of specimens measured 10.

Material: 30 specimens.

Occurrence: *Alveosphaera* ? *densisporata* was recovered from the Buildwas and lower Coalbrookdale formations of the Wenlock type area (Sheinwoodian).

Previously *Alveosphaera* ? *densisporata* has been recorded from the late Llandovery and earliest Wenlock of Austria (Priewalder 1987).

Alveosphaera sp. A

(Pl. 11, fig. 8)

Description

A small spherical species of *Alveosphaera* with relatively large discrete pores which are few in number. *A.*? *deflandrei* (Stockmans & Willière) Priewalder 1987 has more pores which are much smaller.

Dimensions: Populations from the Lower Hill Farm and Eastnor Park boreholes (in microns): width of vesicle 20-26, size of pore approximately 2. Number of specimens measured 3.

Material: 21 specimens.

Occurrence: *Alveosphaera* sp. A was recovered from the Coalbrookdale Formation of both the Lower Hill Farm and Eastnor Park boreholes. (Sheinwoodian to Homerian).

Genus *Helosphaeridium* Lister 1970

Type Species: by original designation *Helosphaeridium clavispinulosum* Lister 1970.

Diagnosis: Lister 1970, p. 76.

Remarks: The important distinguishing feature of Helosphaeridium is that the processes, which are quite diverse in size and shape, 'flare distally in a claviform fashion'.

In the original diagnosis Lister (1970, p.76) stated that excystment is by crypto-suture; in studied specimens of Helosphaeridium median splits were commonly observed, this appearing to be a standard excystment mechanism

Helosphaeridium citrinipeltatum (Cramer & Diez 1972a) Dorning 1981a

(Pl. 11, figs. 9-11)

1972a Lophosphaeridium citrinipeltatum Cramer & Diez, p.166, pl.35, figs. 58,59.

1981a Helosphaeridium citrinipeltatum (Cramer & Diez); Dorning comb. nov. , p.181.

Remarks

Helosphaeridium citrinipeltatum is characterized by numerous low peltate sculptural elements. Excystment is by a median split. Lophosphaeridium citrinum Downie 1963 which is similar in size and process distribution has a granulate ornament.

Dimensions: Populations from the Wenlock type area, Eastnor Park borehole and Dolyhir (in microns): width of vesicle 27-46, height of sculpture < 1. Number of specimens measured 10.

Material: 623 specimens.

Occurrence: Helosphaeridium citrinipeltatum was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area; the Woolhope

Limestone and Coalbrookdale Formation of the Eastnor Park borehole, and the Dolyhir Limestone of the Old Radnor area (Sheinwoodian to Homerian).

Previously Helosphaeridium citrinipeltatum has been recorded from the late Llandovery of Ohio USA (Cramer & Diez 1972a). In the Welsh Borderlands it has only previously been found in the Purple Shales and Buildwas Formation (Dorning 1981a).

Helosphaeridium echiniformis Priewalder 1987

(Pl. 11, fig. 12)

1987 Helosphaeridium echiniformis Priewalder, pp. 36-37, pl.6, figs. 1-6; pl. 18, fig.4.

Remarks

Helosphaeridium echiniformis is characterized by the presence of short numerous baculate processes; H. clavispinulosum Lister 1970 has a larger vesicle possessing fewer processes. H. citrinipeltatum (Cramer & Diez 1972a) Dorning 1981a has more numerous smaller processes.

Dimensions: Populations from the Lower Hill Farm borehole (in microns): width of vesicle 28-45, height of ornament 1-2. Number of specimens measured 10.

Material: 19 specimens.

Occurrence: Helosphaeridium echiniformis was recovered from the upper Buildwas and lower Coalbrookdale formations of the Lower Hill Farm borehole (Sheinwoodian). H. echiniformis has only previously been recorded from the late Llandovery of Austria (Priewalder 1987).

Helosphaeridium malvernensis Dorning 1981a

(Pl. 11, figs. 13,14)

1981a Helosphaeridium malvernensis Dorning, p. 191, pl. II, fig. 15.

1987 Helosphaeridium cf. malvernense Dorning; Molyneux, p. 305, figs. 2d,e; 3a,b.

1987 Helosphaeridium cf. malvernensis Dorning; Priewalder, p. 37, pl. 6, figs. 7,8.

Remarks

Observed specimens of Helosphaeridium malvernensis conform generally to the original description of Dorning (1981a, p. 191), in that the ornament consists of low micrograna with interspersed, distally blunt, sub-cylindrical processes. One difference is a greater variation in vesicle size in studied specimens. The heteromorphic ornament distinguishes H. malvernensis from other described species of Helosphaeridium.

Dimensions: Populations from the Wenlock type area (in microns): width of vesicle 25-47, height of processes 1-2, width at base of process 1-3. Number of specimens measured 10.

Material: 65 specimens.

Occurrence: Helosphaeridium malvernensis was recovered from the Coalbrookdale Formation of the Wenlock type area, and the upper Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole (Sheinwoodian).

Dorning (1981a) recorded Helosphaeridium malvernensis from the lower and middle Coalbrookdale Formation of the Wenlock type area. Molyneux (1987) recovered Helosphaeridium cf. malvernense from probable early Venlock strata of the Scottish Southern Uplands. Priewalder (1987) recovered H. cf. malvernensis from upper Llandovery strata in Austria.

Helosphaeridium pseudodictyum Lister 1970

(Pl. 12, figs. 2-4)

1970 Helosphaeridium pseudodictyum Lister, pl.8, figs. 9-11, 13, 14, 17; Text-figs. 18d, 18e, 27a.

1983 Helosphaeridium pseudodictyum Lister; Dorning, pl.5, fig. 9.

Remarks

A very distinctive species of Helosphaeridium with an ornament of numerous evenly spaced, small, parallel sided outgrowths which flare distally. H. citrinipeltatum (Cramer & Diez) Dorning 1981a differs in that it lacks the expanded crests to the outgrowths, it also has a more dense ornament than H. pseudodictyum. The presence of a dual ornament of processes and micrograna helps distinguish H. malvernensis Dorning 1981a from H. pseudodictyum.

Dimensions: Populations from the Wenlock type area, the Eastnor Park borehole and Dolyhir (in microns): width of vesicle 25-39, height of ornament < 1. Number of specimens measured 10.

Material: 322 specimens.

Occurrence: Helosphaeridium pseudodictyum was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area; the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole and the Dolyhir Limestone of the Old Radnor area (Sheinwoodian to Homerian).

Previously Helosphaeridium pseudodictyum has been recorded from middle Wenlock to upper Ludlow strata in Shropshire (Lister 1970). Dorning (1983) recovered it from the Wenlock Limestone Formation (late Wenlock) of Dudley in the West Midlands; he records its range in the type areas as being from the base of the Wenlock to the top of the Ludlow (Dorning 1981a).

Genus Leiosphaeridia Eisenack 1958

Type Secies: by original designation Leiosphaeridia baltica Eisenack 1958

Diagnosis: Eisenack 1958, p.4.

Remarks: A very large number of specimens were found apparently belonging to a number of species, but in a genus with so few variable morphological characters, species are not easy to distinguish. Only the two most numerous and positively identifiable species are described here.

Leiosphaeridia wenlockia Downie 1959

(Pl. 13, figs. 2-3)

1959 Leiosphaeridia wenlockia Downie, p.65, pl. 12, figs. 2-4.

Remarks

A very common species typically possessing thick, smooth waxy walls, the surface may show some folding.

Dimensions: Populations from the Wenlock type area (in microns): diameter 22-60. Number of specimens measured 10.

Material: Over 7000 specimens.

Occurrence: Leiosphaeridia wenlockia is a cosmopolitan species and was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area, the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole, the Dolyhir Limestone and Coalbrookdale Formation of the Old Radnor area, the Brinkmarsh Formation of the Tortworth Inlier, the Denbigh Grits and Lower Nantglyn Flags of North Wales and the Nant-ysgollon shales of Central Wales (Sheinwoodian to Homerian).

Downie (1959) first recovered Leiosphaeridia wenlockia from the 'Wenlock Shale' (Coalbrookdale Formation) of England. It has since been widely reported from sediments of different ages worldwide.

Leiosphaeridia laevigata Stockmans & Willière 1963

(Pl. 12, figs. 5,6; Pl. 13, fig. 1; Pl. 30, fig. 1)

1963 Leiosphaeridia laevigata Stockmans & Willière, p. 473-474, pl. III, fig. 28.

Remarks

A large thin-walled species with many characteristic folds of the vesicle wall; the vesicle surface may be smooth or scabrate. Leiosphaeridia laevigata is easily distinguished from L. wenlockia Downie 1959, the latter possessing a smaller thicker-walled vesicle.

Dimensions: Populations from the Tortworth Inlier and Wenlock type area (in microns): width of vesicle 62-80. Number of specimens measured 15.

Material: Over 1000 specimens.

Occurrence: Leiosphaeridia laevigata was recovered from the Coalbrookdale Formation of the Wenlock type area and the Denbigh Grits and Lower Nantglyn Flags of North Wales; it is particularly abundant in the Brinkmarsh Formation of the Tortworth Inlier and the Dolyhir Limestone of the Old Radnor area.

Stockmans & Willière (1963) recovered L. laevigata from the Silurian of Belgium; it has since been widely recorded from sediments of different ages worldwide.

Genus Lophosphaeridium Timofeev ex Downie 1963.

Type Species: Lophosphaeridium rarum Timofeev, 1959; by subsequent designation of Downie (1963, p. 630).

Diagnosis: Downie 1963, p. 630.

Remarks

As currently understood, Lophosphaeridium Timofeev ex Downie, 1963 is a rather imprecise generic category as it embraces vesicles bearing, collectively, a variety of process types, all relatively inconspicuous and according to Downie (1963, p. 630) and Lister (1970, p.76), invariably solid.

However, pilate-processed forms are now attributable to Helosphaeridium Lister, 1970 (p. 76); and for at least some of the forms with short, spinelike processes, Gorgonisphaeridium Staplin, Jansonius & Pocock, 1965 (p. 192) is available. Lophosphaeridium is distinguished from Baltisphaeridium by the former possessing solid processes while the latter possesses relatively long hollow spines.

There is a problem with the excystment mechanisms of Lophosphaeridium, they vary between simple pylomes, cryptosutures and median splits; the latter is seen in Lophosphaeridium sp. A which is here placed provisionally in this genus.

Lophosphaeridium citrinum Downie 1963

(Pl. 13, figs. 4,5; Pl. 36, fig. 5)

1963 Lophosphaeridium citrinum Downie, p.630, pl. 92, fig. 3.

Remarks

The vesicle is typically small and ellipsoidal, with an ornament of low spines (pilae). Excystment is by a median split. Lophosphaeridium micospinosum (Eisenack) Downie 1963 has more numerous and longer spinose processes.

Dimensions: Populations from the Wenlock type area: width of vesicle 20-28, length of spines < 1. Number of specimens measured 10.

Material: 20 specimens.

Occurrence: Lophosphaeridium citrinum was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area.

Downie (1963) previously recovered L. citrinum throughout the Wenlock Shales (Coalbrookdale Formation) of the type area.

Lophosphaeridium microspinosum (Eisenack 1954) Downie 1963

(Pl. 13, figs. 6-9)

1954 *Hystrichosphaeridium microspinosum* Eisenack, pp. 209-210, pl.1, fig. 8.

1959 *Baltisphaeridium microspinosum* (Eisenack); Downie, p.60, pl.10, fig.10.

1963 *Lophosphaeridium microspinosum* (Eisenack); Downie, p. 632, pl.92, fig. 11.

1965a *Baltisphaeridium microspinosum* (Eisenack); Eisenack, p. 136, pl. 13, fig. 8.

1970 *Visbysphaera microspinosa* (Eisenack); Lister, p. 99, pl. 13, figs. 11,12; Text-fig. 19g, m.

1971 *Baltisphaeridium microspinosum* (Eisenack); Kjellström, p. 32, pl. 2, fig. 4.

1973 *Baltisphaeridium microspinosum* (Eisenack); Eisenack *et al*. p. 145.

1973 *Baltisphaeridium microspinosum* (Eisenack); Rauscher, p. 161, pl. 9, fig. 15.

1985 *Visbysphaera microspinosa* (Eisenack); Hill *et al*., p.36, pl.11, figs. 7-9, 11.

1987 *Visbysphaera* cf. *microspinosa* (Eisenack); Priewalder, pp. 62-63, pl.16, figs. 2-4; pl.21, fig. 4.

Remarks

Lister (1970, p.99) in his remarks for *Visbysphaera microspinosa* states that forms he encountered had the same vesicle shape, size and wall structure of other forms he had attributed to Visbysphaera. He does not say whether the processes of studied specimens where heteromorphic a feature which is included within the generic diagnosis of Visbysphaera. Lister made a case for retaining specimens with very reduced spines in Lophosphaeridium; as it appears that the illustrated specimens (Lister 1970, pl. 13, figs. 11,12) are the reduced spined forms referred to, they are here included within the synonymy for Lophosphaeridium microspinosum.

Eisenack et al. (1973, p. 146) in additional morphographic material to the original diagnosis of Lophosphaeridium microspinosum (Eisenack 1954, p. 209) refers to specimens possessing numerous, conical, homomorphic processes which are simple with acuminate distal terminations, he does not refer to whether the processes are solid or hollow except to say that there is a proximal plug and that the process does not communicate with the vesicle; a text-figure (Eisenack et al. 1973, p. 145) of a section through a process and the vesicle wall indicates that the processes are solid.

In the present study examined forms possess solid homomorphic spines which are short (less than 1μ in length) and because of this specimens are retained in Lophosphaeridium microspinosum.

Dimensions: Populations from the Wenlock type area (in microns): width of vesicle 50-65, length of spines <1. Number of specimens measured 8.

Material: 30 specimens.

Occurrence: Lophosphaeridium microspinosum was recovered from the middle Coalbrookdale Formation of the Wenlock type area (Sheinwoodian to Homerian).

Eisenack (1954) first described Lophosphaeridium microspinosum from the upper Llandovery of Gotland. In the Wenlock type area Downie (1959,1963) recovered L. microspinosum from the lower and middle ' Wenlock Shales' (Coalbrookdale Formation); Mabillard & Aldridge (1985) record it from the upper Llandovery and lower Wenlock of the Wenlock type area. It has also been found in the Ludlow of the Ludlow type area Lister (1970), the Llandovery of Libya (Hill et al. 1985) and the upper Llandovery of Norway (Dorning & Aldridge 1982)

Lophosphaeridium cf. papillatum (Staplin 1961) Downie 1963

(Pl. 13, figs. 10,11)

cf. 1961 Protoleiosphaeridium papillatum Staplin, pp. 406-407, pl. 48, figs. 10-11.

cf. 1963 Lophosphaeridium cf. papillatum (Staplin); Downie, p. 631, pl. 92, fig. 12.

cf. 1987 Lophosphaeridium papillatum (Staplin); Priewalder, p.39, pl.8, fig. 12,13; pl.19, fig.6. (with synonymy to 1984)

Remarks

Observed specimens possess an ornament of short solid tubercles. The vesicle is circular to sub-triangular and excystment is by a median split. The vesicles of studied specimens are considerably smaller than more typical specimens, the size being comparable to Lophosphaeridium cf. papillatum Downie 1963. Lophosphaeridium microspinosum (Eisenack) Downie 1963 possesses many more processes which are spinose.

Dimensions: Populations from the Wenlock type area (in microns): width of vesicle 22-28, height of ornament <2. Number of specimens measured 8.

Material: 35 specimens.

Occurrence: Lophosphaeridium cf. papillatum was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area.

Staplin (1961) recovered Lophosphaeridium papillatum from the Upper Devonian of Alberta (USA). Downie (1963) recovered L. cf. papillatum from the' Wenlock Shales' (Buildwas and Coalbrookdale formations) of the type area.

Lophosphaeridium pulchrum sp. nov.

(Pl. 14, figs. 1-4)

Derivation of Name: *pulchrum* is the Latin adjective for beautiful.

Holotype: Plate 14, fig. 4; MPA 26058, F1, P49. BGS Lower Hill Farm borehole, Shropshire (SO 5817 9788)

Diagnosis

A subspherical species of Lophosphaeridium with numerous solid homomorphic tubercles covering the vesicle surface; the tubercles have rounded to bluntly rounded distal tips, and are hemispherical in shape. Excystment is by a median split.

Description

The tubercles are discrete and the vesicle wall around their base is psilate. Numbers of tubercles on one side of a cyst vary between 30 and 55.

Remarks

Lophosphaeridium pulchrum sp. nov. differs from Lophosphaeridium granulosum (Staplin 1961) in that the latter has a denser and lower ornament on a smaller vesicle. L. citrinum Downie 1963 differs in that it has an ornament of low spines in contrast to tubercles.

Lophosphaeridium papulatum Martin 1983 possesses conical processes and a granular vesicle. Lophosphaeridium cf. papillatum (Staplin) Downie 1963 possesses tubercles which are more angular.

Dimensions: Populations from the Wenlock type area (in microns): diameter of vesicle 28-39 (holotype 32), height of ornament 1-2 (holotype 2), width at base of ornament 1-2 (holotype 2). Number of specimens measured 10.

Material: 25 specimens.

Occurrence: Lophosphaeridium pulchrum was recovered from the Coalbrookdale Formation of the Wenlock type area and the Eastnor Park borehole.

Genus *Moyeria* Thusu 1973b

Type Species: by original designation *Moyeria uticaensis* Thusu 1973b

Diagnosis: Refer to Thusu 1973b p.142.

Remarks

The spiralled crossing low crests on the vesicle surface distinguishes *Moyeria* from all other described genera.

Moyeria uticaensis Thusu 1973b

(Pl. 14, figs. 5,7,8)

1973b *Moyeria uticaensis* Thusu, p.142, pl.2, figs. 18-22

? '1991' *Moyeria telychensis* Dorning & Hill (in press), p.15, pl.7, fig.5.

Remarks

Crossing of the spiralled crests produces a reticulate ornamented pattern, this combined with the subspherical rather than ovoidal vesicle helps distinguish *Moyeria uticaensis* from *M. cabotii* (Cramer) Miller & Eames 1982. *Moyeria telychensis* Dorning & Hill '1991' (in press) is of the same dimensions as *M. uticaensis* and appears to possess the same ornament, it is therefore considered to be a possible junior synonym of *M. uticaensis*.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): diameter of vesicle 25-42, spacing between striae 1-2. Number of specimens measured 9.

Material: 9 specimens

Occurrence: *Moyeria uticaensis* was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole. Thusu

(1973b) first recovered it from Wenlock strata in New York state USA. Dorning & Hill '1991' (in press) recovered M. telychensis from the Wych Beds (late Llandovery) of the Malvern Hills.

Genus Nanocyclopia Loeblich & Vicander 1976

Type Species: by original designation Nanocyclopia aspratilis Loeblich & Vicander 1976.

Diagnosis: Refer to Loeblich & Vicander 1976, p.19.

Remarks: Specimens of Nanocyclopia typically possess a large central cyclopyle with a thickened margin; an operculum may or may not be present. Schismatosphaeridium Staplin et al. 1965 differs in possessing a smaller pore on one surface and a split on the other.

Nanocyclopia sp. A

(Pl. 14, fig. 9)

Description
Vesicle subspherical possessing irregular folds on the surface, vesicle wall smooth to micrograngulate. Pylome large spherical and appearing slightly darker than the rest of the vesicle wall.

Remarks
Nanocyclopia sp. A does not possess the distinct pitted and granulate ornament of N. pertonensis Dorning & Hill '1991' (in press) or N. storridgensis Dorning & Hill '1991' (in press); and the vesicle is smaller than that of N. woolhopensis Dorning & Hill '1991' (in press).

Dimensions: Populations from the Eastnor Park borehole (in microns): vesicle diameter 25-32, diameter of pylome 15-21. Number of specimens measured 2.

Material: 2 specimens.

Occurrence: Nanocyclopia sp. A was recovered from the Woolhope Limestone of the Eastnor Park borehole.

Genus Psenotopus Tappan & Loeblich 1971

Type species: by original designation Psenotopus chondrocheus Tappan & Loeblich 1971.

Diagnosis: Refer to Tappan & Loeblich 1971, p. 406.

Remarks

The specimens of Psenotopus chondrocheus illustrated by Tappan & Loeblich (1971, pl.11, figs.1,3.) appear to possess trilete marks which would indicate that the taxon is an ornamented spore. This feature was not observed on studied specimens.

Psenotopus chondrocheus Tappan & Loeblich 1971

(Pl. 14, figs. 6, 10-11)

1971 Psenotopus chondrocheus Tappan & Loeblich, p. 406, pl.10, figs. 1-6.

Remarks

Psenotopus chondrocheus does not compare closely with any described acritarch. The ornament of localized tubercles separated by bare or bald areas distinguishes it from any other described taxon. One feature observed on studied specimens was a folding of the vesicle wall, it would appear that the unornamented area of the vesicle wall is thinner and is therefore more susceptible to this.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): maximum diameter of vesicle 55-76. Number of specimens measured 8.

Material: 31 specimens.

Occurrence: Psenotopus chondrocheus was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and from the Woolhope Limestone of the Eastnor Park borehole (Sheinwoodian to Homerian).

Tappan & Loeblich (1971) first described Psenotopus chondrocheus from the Silurian of Indiana USA; Dorning (1981a) recovered it from the upper Wenlock Limestone of the Wenlock type area.

Genus Schismatosphaeridium Staplin, Jansonius & Pocock 1965

Type species: by original designation Schismatosphaeridium perforatum Staplin, Jansonius & Pocock, 1965.

Diagnosis: Refer to Staplin, Jansonius & Pocock, 1965, p. 167

Remarks: Schismatosphaeridium is characterized by a subspherical vesicle which possesses a central pore on one surface and a split on the opposite one.

Schismatosphaeridium longhopensis Dorning 1981a

(Pl. 15, figs. 1-4)

1981a Schismatosphaeridium longhopensis Dorning, p.199, pl. III, figs. 1,2.

Remarks

Observed specimens conform to the original description of Dorning (1981a, p. 199), possessing a small laevigate vesicle with the characteristic pore on one surface and a split on the other. Schismatosphaeridium perforatum Staplin, Jansonius & Pocock 1965 is larger, with a longer split.

Dimensions: Populations from the Wenlock type area and the Eastnor Park borehole (in microns): vesicle diameter 22-28, width of pore 2-3, length of split 12-16. Number of specimens measured 8.

Material: 38 specimens.

Occurrence: Schismatosphaeridium longhopensis was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone of the Eastnor Park borehole (Sheinwoodian to Homerian).

Dorning (1981a) recovered S. longhopensis from the Coalbrookdale Formation of May Hill, Gloucestershire; in the Wenlock type area he recovered it from the Wenlock Limestone and Elton Beds (upper Wenlock to lower Ludlow).

Schismatosphaeridium rugulosum Dorning 1981a

(Pl. 15, figs. 5-9)

1981a Schismatosphaeridium rugulosum Dorning, p.199, pl. III, figs. 1,2.

Remarks

The characteristic morphological feature of this species is the possession of a rugulate to foveolate vesicle wall.

Schismatosphaeridium perforatum Staplin, Jansonius & Pocock 1965 is laevigate with a smaller pore.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle diameter 36-45, diameter of pore 7-10, length of split 22-28. Number of specimens measured 8.

Material: 12 specimens

Occurrence: Schismatosphaeridium rugulosum was recovered from the Buildwas and Coalbrookdale formations of the Venlock type area and the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole (Sheinwoodian).

Dorning (1981a) recovered S. rugulosum from the Purple Shales, and the Buildwas and Coalbrookdale formations (late Llandovery to mid Venlock) of the Venlock type area; Smelror (1986) recorded its range as late Llandovery to mid Venlock in Norway.

Schismatosphaeridium papillatum sp. nov.

(Pl. 15, figs. 10-11)

Derivation of Name: from the latin *papilla* meaning nipple-like protuberance.

Holotype: Plate 15, figs. 10 ;MPA 26076, F1, U44/4. BGS Lower Hill Farm borehole, Shropshire (SO 5817 9788).

Diagnosis

Vesicle sub-spherical with a pore on one surface and a split on the other. The vesicle wall is covered with tubercles which are larger and better developed equatorially, the central region around the pore is microgranulate to laevigate.

Description

The tubercles are of an irregular hemispherical shape, some possess overlapping bases while others are entire and discrete, the number of tubercles varies between 23 and 30. The pore margin on observed specimens appears to be thickened giving it a darkened appearence

Remarks

Schismatosphaeridium rugulosum Dorning 1981a possesses an ornament that is not as well developed and that does not show any topographical preference. The tubercular ornament of Schismatosphaeridium papillatum sp. nov. distinguishes it from any other described species of Schismatosphaeridium.

Although only three specimens were encountered, similar specimens have been observed by Mr. K.J. Dorning (pers. comm.).

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle diameter 25-32 (holotype 30), height of ornament 0.5-2 (holotype 0.5-2). Number of specimens measured 3.

Material: 3 specimens.

Occurrence: *Schismatosphaeridium papillatum* was recovered from the Buildwas Formation of the Lower Hill Farm borehole and the Coalbrookdale Formation of the Eastnor Park borehole.

Subgroup _Acanthomorphitae_ Downie, Evitt & Sarjeant 1963

Genus _Ammonidium_ Lister 1970

Type Species: by original designation _Baltisphaeridium microcladum_ Downie 1963.

Diagnosis: Refer to Lister 1970, p.48.

Remarks

Ammonidium differs from _Multiplicisphaeridium_ Staplin 1961 in exhibiting only one order of process branching, this always being at the distal tip of the processes.

Ammonidium gracilis sp. nov.

(Pl. 16, figs. 1-3)

Derivation of name: from the Latin *gracia* meaning graceful.

Holotype: Plate 16, fig.1 ;MPA 26057, F2, H39/3. BGS Lower Hill Farm borehole, Shropshire (SO 5817 9788).

Diagnosis

A small vesicle, spherical to ellipsoidal and single walled. The vesicle wall is microgranulate. Processes are numerous (20-32) and are up to 75% of the diameter of the vesicle in length, they are widest proximally and taper distally. The most distal tip forks in a trifurcate or quadrifurcate manner.

Remarks

Ammonidium microcladum (Downie) Lister 1970 possesses a much larger vesicle which has longer processes and a more obviously granulate vesicle. _Ammonidium waldronense_ (Tappan & Loeblich) Dorning 1981a possesses a larger vesicle with longer processes; Ammonidium palmitella (Cramer & Diez) Dorning 1981a possesses a larger vesicle which has more numerous processes.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle diameter 18-23, process length 13-16. Number of specimens measured 12.

Material: 398 specimens.

Occurrence: Ammonidium gracilis sp.nov. was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole.

Ammonidium granulosum sp. nov.

(Pl. 16, figs. 5-6)

Derivation of Name: from the Latin *granum* meaning granular.

Holotype: Plate 16, figs. 5-6; VC/PS 12, VF1, X49/4, Whitwell Coppice, Shropshire (SO 6194 0204).

Diagnosis: The vesicle is spherical to ellipsoidal and the vesicle wall is granulate. Processes are short, numerous, evenly spaced and rigid, communicating freely with the vesicle cavity; distally the processes branch in a trifurcate or quadrifurcate fashion. Excystment is by a median split.

Description: Processes typically flare proximally, they are laevigate for their entire length and around the process base; the granulation is well developed and entire over the rest of the vesicle surface.

Remarks

Ammonidium granulosum sp. nov. differs from Ammonidium palmitella (Cramer & Diez) Dorning 1981a in that the latter possesses a laevigate vesicle. A.

microcladum (Downie) Lister 1970 has longer processes which are less numerous and A. waldronense (Tappan & Loeblich) Dorning 1981a has a laevigate vesicle and longer, less numerous processes than A. granulosum sp. nov.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 32-38 (holotype 35), process length 5-8 (holotype 5-6). Number of specimens measured 3.

Material: 12 specimens.

Occurrence: Ammonidium granulosum sp. nov. was recovered from the Coalbrookdale Formation of the Wenlock type area (Sheinwoodian to Homerian).

Ammonidium microcladum (Downie 1963) Lister 1970

(Pl. 16, figs. 7-8; Pl. 31, figs. 1-2)

1963 Baltisphaeridium microcladum Downie, p. 645, pl.91, fig.3, pl.92, fig.6, text-fig. 3g.

1967 Baltisphaeridium microcladum Downie; Lister & Downie, p.173.

1970 Ammonidium microcladum (Downie); Lister, p.49, pl.1, figs. 1-5,7-11; text-fig. 17 a-d.

1987 Ammonidium microcladum (Downie) Lister; Priewalder, p.24, pl.1, fig.13; pl.2, figs. 1-3. (with synonymy to 1983).

Remarks

There is quite a variation in process type in Ammonidium microcladum from specimens with etiolated tapering processes to those with thicker processes. Some observed specimens possess heteromorphic processes with some typically forking distally, while others are simply tapered.

Ammonidium palmitella (Cramer & Diez) Dorning 1981a possesses much shorter and more numerous processes than A. microcladum. A. waldronense (Tappan and Loeblich) Dorning 1981a possesses a laevigate vesicle whereas A. microcladum possesses a granular vesicle.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 24-35, process length 12-22. Number of specimens measured 10.

Material: 484 specimens.

Occurrence: Ammonidium microcladum was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area, the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole, the Nant-ysgollon Shales of Central Wales, and the Dolyhir Limestone of the Old Radnor area.

Downie (1963) first described Ammonidium microcladum from the 'Wenlock Shales' (Buildwas and Coalbrookdale formations) of the type area, Lister (1970) recovered it from the Buildwas Formation. It has also been recorded from Wenlock strata in France (Rauscher & Robardet 1975), Scotland (Dorning 1982), Dudley in the West Midlands (Dorning 1983), Norway (Smelror 1986), Austria (Priewalder 1987) and North Eastern England (Barron 1989).

Ammonidium palmitella (Cramer & Diez 1972a) Dorning 1981a

(Pl. 16, figs. 9-10; Pl. 34, fig. 1)

1972a Baltisphaeridium palimitella Cramer & Diez, p.153, pl.33, fig. 27-30.

1981a Ammonidium palmitella (Cramer & Diez); Dorning, p.183.

Remarks

In the original diagnosis (Cramer & Diez 1972a, p.154) the process length was limited to 30 to 75% of vesicle diameter; in observed specimens the process length is in the range of 10 to 55%, the vesicle is typically spherical and laevigate. Both A. microcladum (Downie) Lister 1970 and A.

waldronense (Tappan & Loeblich) Dorning 1981a possess much longer processes, A. microcladum also has a granular vesicle.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 20-34, length of processes 5-11. Number of specimens measured 10.

Material: 72 specimens.

Occurrence: Ammonidium palmitella was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and from the Woolhope Limestone of the Eastnor Park borehole. (Sheinwoodian to Homerian).

Cramer & Diez (1972a) first recovered Ammonidium palmitella from the late Llandovery of Kentucky USA, it has also been recorded from the latest Llandovery of Bohemia (Dufka & Pacltova 1988); Dorning (1981a) recovered it from the upper Llandovery Purple Shales of the Welsh Borderlands.

Ammonidium waldronense (Tappan & Loeblich 1971) Dorning 1981a

(Pl. 16, fig. 4; Pl. 34, fig. 3)

1971 Caiacorymbifer waldronensis Tappan & Loeblich, p.392, pl.3, figs. 1-8.

1972a Michrystridium clarkii Cramer & Diez, p.167, pl.36, figs. 64-66.

1976 Multiplicisphaeridium waldronensis (Tappan & Loeblich); Eisenack, p. 487.

1981a Ammonidium waldronense (Tappan & Loeblich); Dorning n. comb. , p.183.

1983 Ammonidium waldronense (Tappan & Loeblich) Dorning; Dorning , p.33, pl.5, fig.1.

1984 Ammonidium waldronense (Tappan & Loeblich) Dorning; Armstrong &

Dorning, p.99, pl.1, figs. 3,9.

1987 Ammonidium waldronense (Tappan & Loeblich) Dorning; Priewalder , p. 25, pl.2, figs. 4,5.

1989 Ammonidium waldronense (Tappan & Loeblich) Dorning; Barron, p.85, fig. 3A.

Remarks

Ammonidium waldronense typically possesses more processes than *A. microcladum* (Downie) Lister 1970, the former also has a laevigate vesicle compared to the granulate to verrucate vesicle wall of the latter. *A. palmitella* (Cramer & Diez) Dorning 1981a has shorter more numerous processes than *A. waldronense*. *A. granulosum* sp.nov. in contrast has a granular vesicle and shorter processes. *A. gracilis* sp.nov. is a lot smaller than *A. waldronense*.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): diameter of vesicle 29-38, length of processes 6-9. Number of specimens measured 10.

Material: 434 specimens.

Occurrence: *Ammonidium waldronense* was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone of the Eastnor Park borehole (Sheinwoodian to Homerian).

A. waldronense was first recorded from the late Wenlock of Indiana USA (Tappan & Loeblich 1971), it has also been recovered from the Wenlock of Greenland (Armstrong & Dorning 1984), the mid-Wenlock of N.E. England (Barron 1989), the late Llandovery and early Wenlock of Austria (Priewalder 1987) and from the latest Llandovery of Bohemia (Dufka & Pacltova 1988). Dorning 1981a recorded *A. waldronense* in the Wenlock type area from the Coalbrookdale Formation, Wenlock Limestone and Elton Beds (mid Wenlock to early Ludlow); he also recovered it from the Wenlock Limestone of Dudley in the West Midlands (Dorning 1983).

Genus Cymbosphaeridium Lister 1970

Type Species: by original designation Cymbosphaeridium bikidium Lister 1970.

Diagnosis: Refer to Lister 1970, p.63.

Remarks

Oppilatala Loeblich & Wicander 1976 is similar to Cymbosphaeridium in that it possesses a double vesicle wall, but the constriction at the proximal end of the process caused by separation of the walls is tapering in Oppilatala and straight in Cymbosphaeridium. There is also a difference in process type between the two genera: Cymbosphaeridum has several tubular processes with cauliflorate distal tips while the processes of Oppilatala are thinner and branch more profusely; also Oppilatala excysts by means of a median split while Cymbosphaeridium possesses a circular pylome.

Cymbosphaeridum gueltaense (Jardinē et al. 1974) Dorning 1981a.

(Pl. 16, fig. 11; Pl. 17, fig. 1)

1974 Baltisphaeridium gueltaense Jardinē, Combaz, Magloire, Peniguel & Vachey, p. 122, pl.111, fig.1.

1981a Cymbosphaeridum gueltaense (Jardinē et al.); Dorning, p. 186.

1983 Cymbosphaeridum gueltaense (Jardinē et al.) Dorning; Dorning, pl.5, fig.6.

Remarks

Observed specimens of Cymbosphaeridium gueltaense possess a distinctly dark and granular central vesicle. Processes number 6-10 and are, tubular and distally ramifying; the processes are faintly granular, the ornamentation being especially well developed proximally in the area of connection between vesicle and process.

Dimensions: Populations from the Eastnor Park borehole (in microns): vesicle diameter 36-46, length of processes 32-43. Number of specimens measured 6.

Material: 6 specimens.

Occurrence: *Cymbosphaeridum gueltaense* was recovered from the Woolhope Limestone of the Eastnor Park borehole. It was first recorded from the Ludlow of the Algerian Sahara (Jardiné *et al*. 1974). Dorning (1981a) recorded its range in the type areas of the Welsh Borderlands from mid Wenlock to late Ludlow (Coalbrookdale Formation through to the Leintwardine Beds); he also recovered it from the Wenlock Limestone of Dudley in the West Midlands (Dorning 1983).

Cymbosphaeridium ravum (Downie 1963) Dorning 1981a

(Pl. 17, fig. 4)

1963 *Baltisphaeridium ravum* Downie, p.643, pl.91, fig.6; text-fig. 3c.

1981a *Cymbosphaeridium ravum* (Downie); Dorning, p. 186.

Remarks

Cymbosphaeridium ravum possesses a different style of process branching and fewer processes than *C. pilar* (Cramer) Lister 1970. *C. ravum* also possesses a laevigate rather than a granulate vesicle which distinguishes it from *C. gueltaense* (Jardiné *et al*. 1974) Dorning 1981a. Excystment is characteristically by a pylome.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle diameter 50-60, process length 32-24.
Number of specimens measured 10.

Material: 386 specimens.

Occurrence: Cymbosphaeridium ravum was recovered from the Buildwas and Coalbrookdale formations of the Venlock type area and from the Coalbrookdale Formation of the Eastnor Park borehole (Sheinwoodian).

Cymbosphaeridium ravum was first recorded from the Buildwas and Coalbrookdale formations of the Venlock type area (Downie 1963). Dorning (1981a) recorded C. ravum from the Purple Shales, Buildwas and lower Coalbrookdale formations of the type area.

Cymbosphaeridium cf. eurnes (Cramer & Diez 1972a) Dorning 1981a

(Pl. 17, figs. 2-3; Pl. 34, fig. 6)

cf. 1972a Baltisphaeridium eurnes Cramer & Diez, p. 150, pl.32, fig. 12.

cf. 1981a Cymbosphaeridium eurnes (Cramer & Diez); Dorning, p.186.

Remarks

Observed specimens possess a spherical central body and thick tube-like processes with bifurcated distal terminations which are dagger like in form. The specimens differ from typical forms of C. eurnes in that processes are fewer, the vesicle is faintly granulate and the proximal process constrictions are tapering (extending up the processes), rather than being straight. Cymbosphaeridium gueltaense (Jardine et al. 1974) Dorning 1981a is smaller and has a more ornamented vesicle.

Dimensions: Populations from the Venlock type area (in microns): vesicle diameter 45-57, length of processes 52-76. Number of specimens measured 10.

Material: 11 specimens.

Occurrence: Cymbosphaeridium cf. eurnes was recovered from the Buildwas and Coalbrookdale formations of the Venlock type area (Sheinwoodian to Homerian).

Cymbosphaeridium eurnes was first recovered from upper Venlock strata in Indiana USA (Cramer & Diez 1972a). Dorning (1981a) reported it from the Venlock Limestone and Elton Beds of the Venlock type area (late Venlock to early Ludlow); it was also recorded from the Venlock Limestone of Dudley in the West Midlands (Dorning 1983).

Genus *Dateriocradus* Tappan & Loeblich 1971

Type Species: by original designation *Dateriocradus polydactylus* Tappan & Loeblich 1971.

Diagnosis: Refer to Tappan & Loeblich p.394.

Remarks

Dateriocradus differs from species of *Veryhachium* (Deunff 1954) in that processes branch distally in the former, whereas in *Veryhachium* the processes are unbranched.

Dateriocradus algerensis (Cramer & Diez 1972a) Dorning 1981a

(Pl. 17, figs. 6-7; Pl. 34, fig. 5)

1972a *Veryhachium europaeum algerensis* Cramer & Diez, p.173, pl.36, fig.74.

1981a *Dateriocradus algerensis* (Cramer & Diez); Dorning n. comb. , p.186.

Remarks

Branching of processes in *Dateriocradus algerensis* is up to two orders, the initial branching of the processes is always in the distal half. There is a free connection between hollow process and vesicle.

D. monterossae (Cramer) Dorning 1981a possesses much wider processes that typically do not branch as much as those of *D. algerensis*.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle diameter 25-36, length of processes 51-62. Number of specimens measured 8.

Material: 26 specimens.

Occurrence: *Dateriocradus algerensis* was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole. *D. algerensis* was first recovered from upper Llandovery strata of Ohio USA (Cramer & Diez 1972). Dorning 1981a recorded it in the Wenlock type area from the Buildwas Formation.

Dateriocradus monterossae (Cramer 1969a) Dorning 1981a

(Pl. 17, figs. 10-11)

non. 1964 *Baltisphaeridium molinum* Cramer, p.297,298, pl. VI, figs. 5,7; pl. VII, fig.9.

1969a *Baltisphaeridium monterossae* Cramer, p.490, pl.1, figs. 5-7, figs.: 1d,e,f.

1970 *Baltisphaeridium monterossae* Cramer; Cramer, p. 129, pl.VIII, figs. 127-132, 135; text-fig 39j.

1981a *Dateriocradus monterossae* (Cramer); Dorning n. comb., p.186.

Remarks

Observed specimens conform to the emended diagnosis (Cramer 1970, p.129). The relatively short cylindrical process with broad conical bases and the simple branching (up to 2nd order) distinguish *Dateriocradus monterossae* from *D. algerensis* (Cramer & Diez) Dorning 1981a and *D. polydactylus* Tappan & Loeblich 1971.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): diameter of vesicle 22-30, length of processes 25-33. Number of specimens measured 8.

Material: 13 specimens.

Occurrence: *Dateriocradus monterossae* was recovered from the Coalbrookdale Formation of the Wenlock type area and the Woolhope Limestone of the Eastnor Park borehole (Sheinwoodian). It has previously been recovered from Wenlock strata in the USA (Cramer 1969a, 1970), in NW Spain (Cramer 1964) and in Belgium (Martin 1966).

Dorning (1981a) previously recorded *D. monterossae* in the Wenlock type area from the upper Buildwas and lower Coalbrookdale formations (Sheinwoodian).

Genus *Diexallophasis* Loeblich 1970

1970 *Diexallophasis* Loeblich, p. 714.

1970 *Evittia* Lister, p.67.

Type species: by original designation *Baltisphaeridium denticulata* Stockmans & Willière 1963

Diagnosis: Refer to Loeblich 1970, p.714.

Remarks: The essential characteristics of *Diexallophasis* are the irregularly spaced granules on the vesicle and on the processes. Some species have simple processes while others have branched.

Diexallophasis denticulata (Stockmans & Willière 1963) Loeblich 1970.

(Pl. 31, figs. 3-7)

1963 *Baltisphaeridium denticulatum* Stockmans & Willière, p. 458, pl.13 figs. 1,4.

1963 *Baltisphaeridium granulatispinosum* Downie, p. 640, pl. 91. figs. 1,7.

1966a *Baltisphaeridium denticulatum* Stockmans & Willière, forma *rigidium* ; Cramer, p.36, pl.3, figs. 6-8.

1969 *Diexallophasis denticulata* (Stockmans & Willière); Loeblich n. comb, p.715.

1970 *Evittia granulatispinosa* (Downie); Lister, p.67, pl.4, figs. 2,3,5-9, 12; pl.5, fig.2.

1972a *Baltisphaeridium denticulatum* Stockmans & Willière; *indianae* n. var. Cramer & Diez, p.149, pl.32, fig.17.

1973 *Multiplicisphaeridium denticulatum* (Stockmans & Willière); Eisenack *et al*., p.587.

1973 *Multiplicisphaeridium denticulatum denticulatum* (Cramer); Eisenack *et al*., p.593.

1973 *Multiplicisphaeridium denticulatum gotlandicum* (Cramer); Eisenack *et al*., p.595.

1973 *Multiplicisphaeridium denticulatum ontariensis* (Cramer); Eisenack *et al*., p.599.

1973 *Multiplicisphaeridium denticulatum rigidium* (Cramer); Eisenack *et al*., p. 601.

1973 *Multiplicisphaeridium denticulatum simplex* (Cramer); Eisenack *et al*., p. 603.

1979 Multiplicisphaeridium denticulatum granulosum Eisenack et al., p.50, fig. 18c.

1986 Diexallophasis denticulata (Stockmans & Willière) Loeblich; Smelror, pl.I, figs. 1,2.

1987 Diexallophasis denticulata (Stockmans & Willière) Loeblich; Priewalder, p. 31, pl.4, figs. 7-11; pl.5, fig. 1,2.

Remarks

Diexallophasis denticulata constitutes a group of acritarchs with a morphological gradation through forms with a sparse granulate ornamentation possessing a few simply branched processes, to forms with a well developed ornamentation and more numerous and complexly branched processes; there are also marked variations in topographical preferences of the ornamentation between process and vesicle on observed specimens.

There have been many attempts to split this large group at the sub-specific level (see Eisenack et al. 1973, pp. 587-603) but with gradational forms between morphological 'end members' and no distinct split caused by stratigraphical range differences, observed specimens here are all classified in D. denticulata.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 18-42, length of processes 18-62, process number 3-20. Number of specimens measured 10.

Material: 2495 specimens.

Occurrence: Diexallophasis denticulata was recovered fron the Buildwas and Coalbrookdale formations of the Wenlock type area the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole, the Denbigh Grits and Lower Nantglyn Flags of North Wales, the Nant-ysgollon Shales of Central Wales, the Dolyhir Limestone of the Old Radnor Area and the Brinkmarsh Formation of the Tortworth Inlier. Previously D. denticulata has been recovered from strata of early Llandovery to early Gedinnian age in Europe and North America.

Genus Eisenackidium Cramer & Diez 1968 emend. Eisenack et al. 1973

1968 Eisenackidium Cramer & Diez, pp.558-559.

1970 Crameria Lister, p.61.

Type species: by original designation Eisenackidium triplodermum Cramer & Diez 1968.

Diagnosis: Refer to Eisenack et al. 1973, p.435.

Remarks: Specimens of Eisenackidium are double-walled and are characterized by a spherical to subtriangular vesicle and the possession of a few simple tapering or digitate processes (3-12) each possessing a central fold running down the process length. The outer wall is often, thin flimsy and poorly attached to an inner thick, rigid wall. Estiastra Eisenack 1959 is larger, single walled and does not possess the longitudinal folds.

Eisenackidium wenlockensis Dorning 1981a

(Pl. 17, figs. 5,8)

1981a Eisenackidium wenlockensis Dorning, p.188, pl.II, fig.12.

1983 Eisenackidium wenlockensis Dorning; Dorning, pl.6, fig.7.

Remarks

Observed specimens are double-walled, the inner wall is thick and rigid, and the outer wall is thin, flimsy and poorly attached to the inner wall, all specimens possess simple unbranched processes which taper distally from a wide base; central longitudinal folds run the length of the processes and are probably a result of folding of the outer wall. E.

ludlovensis Dorning 1981a differs in having longer processes and a smaller vesicle.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 26-32, length of processes 16-22, width of processes at base 4-8, number of processes 5-8. Number of specimens measured 5.

Material: 5 specimens.

Occurrence: *Eisenackidium wenlockensis* was recovered from the mid-Coalbrookdale Formation of the Wenlock type area (early Homerian).

Dorning (1981a,1983) recovered *E. wenlockensis* from the Wenlock Limestone of the type area and from Dudley in the West Midlands.

Genus *Estiastra* Eisenack 1959

Type species: by original designation *Estiastra magna* Eisenack 1959.

Diagnosis: Refer to Eisenack 1959, pp. 201-202.

Remarks: *Estiastra* is differentiated from *Pulvinosphaeridium* Eisenack 1954 in that the processes form acute angles in *Estiastra* (star shaped) whereas in *Pulvinosphaeridium* processes are rounded (pillow shaped) and connect to form a central cavity.

Estiastra barbata Downie 1963

(Pl. 22, fig. 3; Pl. 35, fig. 5)

1963 *Estiastra barbata* Downie, pl.92, fig.8.

1966 *Estiastra barbata* Downie; Martin, p.317, pl.I, fig.27.

1970 *Estiastra barbata* Downie; Cramer, p.118, fig.34f.

1973 *Estiastra barbata* Downie; Cramer, p.451.

1981a *Tylotopalla barbata* (Downie); Dorning, p.182.

1989 *Estiastra barbata* Downie; Barron, p. 87.

Remarks

A star shaped acritarch possessing conical processes some with digitate ends. Processes are ornamented with small spines and grana. Dorning (1981a, p. 182) stated, incorrectly, that Eisenack *et al*. (1973) transferred this species to *Tylotopalla* Loeblich 1970. The species belongs in *Estiastra* Eisenack 1959, as the central portion of the test is formed from the bases of the processes, unlike *Tylotopalla* where the processes are differentiated from the circular to subcircular central body. *Estiastra granulata* Downie 1963 has more processes and is generally larger and *E. magna* Eisenack 1959 is much smaller than *E. barbata*.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle diameter 90-115, number of processes 4-8. Number of specimens measured 9.

Material: 70 specimens.

Occurrence: *Estiastra barbata* was recovered from the Buildwas Formation of the Wenlock type area and the Woolhope Limestone of the Eastnor Park borehole.

E. barbata has previously been recovered from upper Llandovery strata in Belgium (Martin 1966, 1968) and from the latest Llandovery and earliest Wenlock of Podolia and the Ukraine (Kirjanov 1978). Downie (1963) first recovered *E. barbata* from the Buildwas Formation of the Wenlock type area; Hill (1974a,b) recorded it from both the Purple Shales and Buildwas Formation (upper Llandovery to lower Wenlock) as did Dorning (1981a) and Mabillard & Aldridge (1985). Barron (1989) recorded *E. barbata* from sediments of a questionable mid-Wenlock age in the Cheviot Hills of NE England.

Estiastra granulata Downie 1963

(Pl. 25, figs. 1-2)

1963 *Estiastra granulata* Downie, p.638, pl.91, fig.8.

1970 *Estiastra granulata* Downie; Cramer, pp. 118-119, fig. 34e.

1969 *Estiastra stellata* Loeblich, p. 720, fig. 14e.

1973 *Estiastra granulata* Downie; Eisenack *et al*., p. 453.

Remarks

Observed specimens possess a typically star-shaped vesicle with 8-12 processes and an ornament of closely packed grana. *Estiastra granulata* superficially resembles *E. magna* Eisenack 1959; the latter though is larger, darker in colour and has a psilate vesicle.

Dimensions: Populations from the Wenlock type area (in microns): total diameter of vesicle 92-135. Number of specimens measured 7.

Material: 7 specimens.

Occurrence: *Estiastra granulata* was recovered from the Coalbrookdale Formation of the Lower Hill Farm borehole (Sheinwoodian to Homerian?)

Downie (1963) first recovered *E. granulata* from the upper Coalbrookdale Formation and Wenlock Limestone of the Wenlock type area; Dorning (1981a, 1983) recovered it from the Wenlock Limestone of the type area and of Dudley in the West Midlands.

Genus *Electoriskos* Loeblich 1969

Type species: by original designation *Electoriskos aurora* Loeblich 1969

Emended diagnosis

The vesicle is spherical to subspherical and the wall is proportionately thin and apparently single layered. The vesicle surface is psilate to granulate with numerous slender, flexible but solid processes which do not communicate with the interior of the vesicle. Processes are mainly simple, some branch once distally.

Remarks

The diagnosis is here emended to include forms with branching processes ;the original diagnosis (Loeblich 1969, p. 717) allows only forms with simple processes to be included within Elektoriskos.

Comasphaeridium Staplin, Jansonius and Pocock 1965 in contrast to Elektoriskos possesses densely crowded hair-like processes.

Elektoriskos williereae (Deflandre & Deflandre-Rigaud 1965) Vanguestaine 1979

(Pl. 17, fig. 9; Pl. 18, fig. 1)

1963 Baltisphaeridium aff. polytrichum (Valensi, 1947); Stockmans & Willière, p. 460, pl.3, figs. 24,25.

1965 Micrhystridium williereae Deflandre & Deflandre-Rigaud, p.111, fig.2.

1966a Baltisphaeridium aff. polytrichum Martin, p.4, text-fig.3.

1967 Micrhystridium willerae Deflandre & Deflandre-Rigaud; Martin , pp. 315, 327 (no fig.)

1968 Micrhystridium willereae Deflandre & Deflandre-Rigaud; Martin , pp. 82-3, pl.4, fig. 175: pl.7, fig. 324; pl.8, fig. 387.

1970 Filisphaeridium williereae (Deflandre & Deflandre-Rigaud); Lister, p.73, pl.7, figs.1-4.

1979 Elektoriskos williereae (Deflandre & Deflandre-Rigaud); Vanguestaine n. comb., p.247, Pl.II, fig.3: Pl.III, fig. 19.

1989 Elektoriskos williereae (Deflandre & Deflandre-Rigaud); Martin, fig.151, A.

Remarks

The vesicle is spherical to subspherical, thin, transparent and psilate with occasional scattered grana. Processes are solid, numerous, long, thin, flexible and sometimes anastomosing, most are simple, others branch once distally.

Elektoriskos brevispinosa (Lister) Dorning 1981a differs in that it has very short processes (up to 10% of the vesicle diameter in length) that do not branch.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle diameter 25-42, length of processes 22-38. Number of specimens measured 10.

Material: 33 specimens.

Occurrence: Elektoriskos williereae was recovered from the Coalbrookdale and Buildwas formations of the Wenlock type area and the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole (Sheinwoodian to Homerian). E. williereae has previously been recovered from strata of late Llandovery to late Ludlow age in Belgium (Stockmans & Willière 1963; Martin 1966, 1967, 1968); Lister 1970 reported its occurrence in the lower Elton Beds and Whitcliffe Beds of Shropshire (Ludlow); Dorning (1981a) recovered it from the Purple Shales and Buildwas Formation of the Wenlock type area (late Llandovery to early Wenlock). Vanguestaine (1979) recovered E. willereae from sediments of Middle Devonian age in Belgium, but presumed specimens to have been reworked from the Silurian. Martin (1989) records the known stratigraphical range of E. williereae as early Llandovery to late Wenlock.

Genus *Florisphaeridium* Lister 1970

Type species: by original designation *Florisphaeridium castellum* Lister 1970.

Diagnosis: Refer to Lister 1970, p.74.

Remarks

The distinctive distal invaginations of the processes separates *Florisphaeridium* from all other described acanthomorph genera.

Florisphaeridium gulletum Dorning & Hill '1991' (in press) emend.

(Pl. 17, fig. 12; Pl. 18, figs. 3,6,10)

'1991' *Florisphaeridium gulletum* Dorning & Hill (in press), p.12, pl.1 fig.9.

Emended diagnosis

Vesicle spherical to subspherical and laevigate, possessing 5-12 extended and tubular processes which flare distally. Excystment is by a median split.

Remarks

The possession of extended and tubular processes distinguishes *F. gulletum* Dorning & Hill '1991' (in press) from *F. wenlockensis* Dorning 1981a and *F. castellum* Lister 1970, both of which have shorter wider processes.

The emendation takes into account the variable number of processes on observed specimens (5-12) in contrast to the recorded 6 processes of the original description. Also included in the emendation is the excystment mechanism which has not been previously recorded.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 23-31, length of processes 5-10, width at base of processes 3-4, width across distal terminations 4-6. Number of specimens measured 10.

Material: 31 specimens.

Occurrence: *Florisphaeridium gulletum* was recovered from the Coalbrookdale Formation of the Lower Hill Farm borehole (Sheinwoodian to Homerian). Dorning & Hill '1991' (in press) recovered *F. gulletum* from the Wych Beds (upper Llandovery) of the Malvern Hills.

Florisphaeridium wenlockensis Dorning 1981a

(Pl. 18, figs. 2,5)

1981a *Florisphaeridium wenlockensis* Dorning, p. 189, pl.III, fig. 10.

Remarks

Observed specimens conform to the original description (Dorning 1981a, p. 189); the excystment mechanism, which has not been noted before, is by a median split.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 30-40, length of processes 3-5, width of processes at the base 3-7, width across distal terminations 5-9. Number of specimens measured 10.

Material: 111 specimens.

Occurrence: *Florisphaeridium wenlockensis* was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area, the Woolhope Limestone of the Eastnor Park borehole and the Brinkmarsh Formation of the Tortworth Inlier (Sheinwoodian to Homerian). Dorning (1981a) recorded it from the Buildwas and Coalbrookdale formations of the Wenlock type area.

Genus *Gorgonisphaeridium* Staplin, Jansonius & Pocock 1965

Type species: by original designation *Gorgonisphaeridium spicatum* Staplin, Jansonius & Pocock 1965.

Diagnosis: Refer to Staplin, Jansonius & Pocock 1965, p.192.

Remarks: *Gorgonisphaeridium* differs from *Multiplicisphaeridium* Staplin 1961 in that it has short solid processes in contrast to longer hollow ones.

Gorgonisphaeridium succinum Lister 1970

(Pl. 18, figs. 7,11,12)

1970 *Gorgonisphaeridium succinum* Lister, p.75, pl.8, figs. 1-4.

1973 *Multiplicisphaeridium succinum* (Lister 1970); Eisenack *et al.*, p. 805.

Remarks

The small vesicle size and complex branching nature of the processes separates *G. succinum* from *G. spicatum* Staplin *et al.* 1965 which is larger with simply bifurcating processes. *G. winslowii* Staplin *et al.* 1965 possesses a larger vesicle than *G. succinum* and has more widely spaced processes that branch only occasionally; *Gorgonisphaeridium bringewoodensis* Dorning 1981a possesses a larger vesicle than *G. succinum* and has only simple processes.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 18-30, process length 3-6, number of processes 12-21. Number of specimens measured 4.

Material: 4 specimens.

Occurrence: *Gorgonisphaeridium succinum* was recovered from the Coalbrookdale Formation of the Wenlock type area (Sheinwoodian to Homerian). Lister (1970) recovered it sporadically through the upper Coalbrookdale Formation, the Wenlock Limestone, the Elton Beds and lower Whitcliffe Beds of Shropshire (mid Wenlock to late Ludlow).

Genus *Gracilisphaeridium* Eisenack *et al*. 1973

Type species: by original designation *Baltisphaeridium encantador* Cramer 1970

Diagnosis: Refer to Eisenack *et al*. 1973, p. 511.

Remarks

The looped pinnae are the distinguishing characteristic features of this genus. *Ammonidium* Lister 1970 in contrast possesses distal furcations of the processes.

Gracilisphaeridium encantador (Cramer 1970) Eisenack *et al*. 1973

(Pl. 18, figs. 4,8-9; Pl. 34, fig. 2)

1970 *Baltisphaeridium encantador* Cramer, pp.189-190, pl.XIX, figs. 296-299; text-fig : 61.

1973 *Gracilisphaeridium encantador* (Cramer); Eisenack *et al*. n. comb. , p.511.

1974b *Ammonidium encantador* (Cramer); Hill, p.11.

1986 *Gracilisphaeridium encantador* (Cramer) Eisenack *et al*.; Smelror, pl.IV, fig.8.

1989 *Gracilisphaeridium encantador* (Cramer) Eisenack *et al*.; Martin, fig. 151, H.

1989 *Gracilisphaeridium encantador* (Cramer) Eisenack *et al*.; Barron, p. 87, fig. 3c.

Remarks

Observed specimens excysted by means of a median split; in the emended diagnosis of Eisenack et al. (1973, p. 514) it is suggested that 'excystment is by means of a circular pylome' although it is stated that 'because nearly all pylome bearing specimens were damaged, pylomes were not positively identified'; there is though reference to 'opercula which bear concentrically arranged processes', this supports the interpretation of pylome excystment. Without observing these specimens and because there are no conclusive illustrations, indication is that if they were correct there is a dual excystment mechanism in this species; it is though more likely that the observations were incorrect and that excystment is only by median split.

A variation observed in the present study is a morphological gradation from forms with typically relatively short wide processes to those with much longer thinner processes; the 'short forms' are similar to those described by Cramer et al. 1979 (p. 42) and Barron 1989 (p. 88).

Proximal constriction of the processes is referred to in a roundabout way in the emended diagnosis (Eisenack et al. 1973, p. 514), the suggestion is that 'in forms which bear a cyst the central vesicle may be separated from the central vesicle cavity by the continuation of the endoderm'. The processes of observed specimens display a feature which was variable even on a single specimen, some processes possess a tapering V shaped plug similar in style to that of Oppilatala Loeblich & Vicander 1976 while some processes are not plugged and appear to communicate freely with the central vesicle.

Gracilisphaeridium is still a monospecific genus, the species being characterized by the very obvious distal looped pinnae; apart from this apparently unique morphological feature there is quite a variation in morphology which is gradational and therefore does not allow at the moment another specific split.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle diameter 22-36, process length 9-25, number of processes 15-22. Number of specimens measured 10.

Material: 51 specimens.

Occurrence: Gracilisphaeridium encantador was recovered from the lower Buildwas Formation of the Lower Hill Farm borehole and the Woolhope Limestone of the Eastnor Park borehole (Sheinwoodian).

G. encantador was first described from the upper Llandovery of Ohio and Kentucky USA (Cramer 1970; Cramer & Diez 1972a). Hill (1974b), Dorning (1981a) and Mabillard & Aldridge (1985) recovered it from the Purple Shales and Buildwas Formation of the Wenlock type area (late Llandovery to early Wenlock); Smelror (1986) recovered it from upper Llandovery strata in Norway; Cramer et al. 1979 and Le Herisse 1984 recorded it from the early Wenlock of Gotland. Barron 1989 recovered a single specimen of G. encantador from sediments of a questionable middle Wenlock age in the Cheviot Hills (NE England), he states that the short forms range up to the middle Wenlock (K.J. Dorning written comm.); in the present study both forms of G. encantador and morphological variations between them occur in the same samples and are restricted to the earliest Wenlock. Martin (1989) records the known stratigraphical range of G. encantador as late Llandovery to early Wenlock.

Genus Hoegklintia Dorning 1981a

Type species: by original designation Baltisphaeridium visbyense Eisenack 1959.

Diagnosis: Refer to Dorning 1981a, p.192.

Remarks

Multiplicisphaeridium is generally smaller and has a thicker wall than Hoegklintia; Estiastra has simple processes; Pulvinosphaeridium has very blunt process terminations.

Hoegklintia ancyrea (Cramer & Diez 1972a) Dorning 1981a

(Pl. 19, figs. 1-2)

1972a Baltisphaeridium ancyreum Cramer & Diez, pp. 147-148.

1981 Hoegklintia ancyrea (Cramer & Diez); Dorning, p.192.

1988 Hoegklintia ancyrea (Cramer & Diez); Eley & Legault, p.58, pl.1, fig.12.

Remarks

The vesicle has a triangular to polygonal outline with 6-8 processes. Distal terminations of processes are rounded and are simple to multifurcate (up to 2nd order). Both furcate and non-furcate processes appear on the same specimens. In contrast Hoegklintia cylindrica (Cramer) Dorning 1981a and Hoegklintia digitatum (Eisenack) Dorning 1981a are both larger species, with different process types.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): diameter of central body 72-83, length of processes 78-92. Number of specimens measured 10.

Material: 11 specimens.

Occurrence: Hoegklintia ancyrea was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and from the Woolhope Limestone of the Eastnor Park borehole.

Cramer & Diez (1972a) first recovered H. ancyrea from upper Llandovery strata in the USA. Dorning (1981a) in the Wenlock type area recovered it from the Purple Shales to the lower Wenlock Limestone (late Llandovery to late Wenlock), he also recorded it from the Wenlock Limestone of Dudley in the West Midlands (Dorning 1983).

Genus Leptobrachion Dorning 1981a

Type species: by original designation Baltisphaeridium arbusculiferum Downie 1963

Diagnosis: Refer to Dorning 1981a, p.193.

Remarks

In contrast to the double walled vesicle and thin-branched tapering processes of Leptobrachion, Multiplicisphaeridium Staplin 1961 has a single walled vesicle, Oppilatala Loeblich & Vicander 1976 has tubular processes with a sharp base and Eisenackidium Cramer & Diez 1968 has simple processes.

Leptobrachion cf. longhopense Dorning 1981a

(Pl. 18, figs. 13-14)

cf. 1981a Leptobrachion longhopense Dorning p.193, pl.1, fig.2.

Remarks

Observed specimens possess fewer processes (5-7) than typical specimens of L. longhopense (8-10), although the small subspherical double-walled vesicles with both simple and multifurcate processes are comparable features. Leptobrachion woolhopense Dorning 1981a and L. malvernia Dorning 1981a both possess a larger vesicle, the latter is also distinguished by the possession of complexly multifurcate processes.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 16-22, process length 28-42. Number of specimens measured 8.

Material: 8 specimens.

Occurrence: Leptobrachion cf. longhopense was recovered from the Coalbrookdale Formation of the Wenlock type area and the Woolhope Limestone of the Eastnor Park borehole.

Dorning (1981a) recovered L. longhopense from the Elton beds (early Ludlow) of the Ludlow type area although he records its type locality as the Coalbrookdale Formation of the May Hill Inlier, Gloucestershire.

Genus *Micrhystridium* Deflandre 1937 emend. Staplin 1961

Type species: by original designation *Micrhystridium inconspicuum* Deflandre 1937.

Diagnosis: Refer to Staplin 1961, p.408.

Remarks
Morphologically a very simple genus possessing a subspherical to polygonal vesicle and simple tapering processes; *Multiplicisphaeridium* Staplin 1961 differs in the possession of branching processes.

Micrhystridium stellatum Deflandre 1945

(Pl. 19, figs. 3-4; Pl. 35, fig. 1)

1945 *Micrhystridium stellatum* Deflandre, p.22, pl.3, figs. 16-19.

1986 *Micrhystridium stellatum* group Deflandre; Smelror, p.145, pl.11, fig.10.

1987 *Micrhystridium stellatum* Deflandre; Priewalder, pp.40-41, pl.7, fig.9; text-fig.15 (with synonymy to 1985).

Remarks
The brief diagnosis of *Micrhystridium stellatum* (Deflandre 1945, p.22) leads to the possibility that it is a 'bucket taxon' covering a large group of species; this is acceptable because the very simple morphology and continous variation between possible end members mean that specific splits are not adequately definable.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 11-19, length of processes 12-23. Number of specimens measured 15.

Material: 3835 specimens.

Occurrence: Micrhystridium stellatum was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area, the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole, the Dolyhir Limestone of the Old Radnor area and the Denbigh Grits of North Wales (Sheinwoodian to Homerian).

M. stellatum is a cosmopolitan taxon with a worldwide distribution and a recorded stratigraphical range from the Upper Ordovician to the Upper Devonian. In the Welsh Borderlands it has previously been recorded from the late Llandovery and early Wenlock by Mabillard & Aldridge (1985).

Micrhystridium eatonensis Downie 1959

(Pl. 18, fig. 15)

1959 Micrhystridium eatonensis Downie, p.62, pl.11, fig.15.

1963 Micrhystridium eatonensis Downie; Downie, p.645.

1970 Micrhystridium eatonensis Downie; Cramer, p.101, fig.28.

Remarks

The small simple stout processes of Micrhystridium eatonensis distinguish it from most other species of Micrhystridium. M. nannacanthum Deflandre 1945 differs in that it possesses thinner more numerous processes and the vesicle diameter is smaller.

Dimensions: Populations from the Tortworth Inlier and the Wenlock type area: vesicle diameter 11-26, process length 1-2.5. Number of specimens measured 10.

Material: 46 specimens.

Occurrence: Micrhystridium eatonensis was recovered from the Brinkmarsh Formation of the Tortworth Inlier, the Dolyhir Limestone and Coalbrookdale Formation of the Old Radnor area and from the Buildwas Formation of the

Lower Hill Farm borehole. Downie (1959, 1963) described it from the Buildwas and Coalbrookdale formations of the Wenlock type area.

Genus Multiplicisphaeridium Staplin 1961

Type species: by original designation Multiplicisphaeridium ramispinosum Staplin 1961

Diagnosis: Refer to Staplin 1961, p.401.

Remarks

Multiplicisphaeridium is characterized by having a single-layered spherical to subspherical vesicle with several to numerous branched processes, the branching being of more than one order; the processes tend to taper distally and do not have a sharp base; neither the vesicle nor process walls have prominent ornamentation.

In contrast Gorgonisphaeridium Staplin et al. 1965 possesses short solid processes. Diexallophasis Loeblich 1970 has less complexly branched processes which are distinctly granular.

Multiplicisphaeridium arbusculum Dorning 1981a

(Pl. 19, figs. 5-6; Pl. 35, fig. 2)

1981a Multiplicisphaeridium arbusculum Dorning, p.194, pl.I, fig.7.

1984 Multiplicisphaeridium arbusculum Dorning; Armstrong & Dorning, pl.1, fig.7.

1987 Multiplicisphaeridium cf. arbusculum Dorning; Priewalder, p.42, pl.7, fig.2; text-fig. 17.

Remarks

Observed specimens are characterized by the possession of 6-12 laevigate processes which branch in an irregular fashion up to fourth order; the first order of branching often occurs about one third to one half along the length of the process.

Multiplicisphaeridium variabile Lister 1970 differs in having more processes and a larger vesicle.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 14-25, length of processes 17-32, width of process base 2-3. Number of specimens measured 10.

Material: 297 specimens.

Occurrence: *Multiplicisphaeridium arbusculum* was recovered from the Coalbrookdale Formation of the Wenlock type area, the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole, the Brinkmarsh Formation of the Tortworth Inlier, the Denbigh Grits of North Wales, the Nant-ysgollon Shales of Central Wales and the Dolyhir Limestone of the Old Radnor area.

Dorning (1981a) first recorded *M. arbusculum* from the Coalbrookdale Formation, Wenlock Limestone and Elton Beds of the Wenlock and Ludlow type areas (mid Wenlock to early Ludlow). It has also been recorded from strata of similar age in Greenland (Armstrong & Dorning 1984), Norway (Smelror 1986), Austria (Priewalder 1987) and NE England (Barron 1989).

Multiplicisphaeridium cladum (Downie 1963) Eisenack 1969

(Pl. 34, fig. 4)

1963 *Baltisphaeridium cladum* Downie, p.643, pl.92, fig.5; text-fig. 3a

1969 *Multiplicisphaeridium cladum* (Downie); Eisenack n. comb., p.260

1970 Baltisphaeridium cladum Downie; Cramer, p.126, pl.8, fig.36; text-fig. 39h.

1982 Multiplicisphaeridium cladum (Downie) Eisenack; Dorning, p.268, pl.1, figs.3,6.

1987 Multiplicisphaeridium cf. cladum (Downie) Eisenack; Priewalder, p.43, pl.9, fig. 5,6; text-fig. 20.

Remarks

Observed specimens of Multiplicisphaeridium cladum possess typically stout processes with rapidly widening bases; the processes branch distally up to third order. It is the process type that distinguishes M. cladum from M. arbusculum, the latter possessing longer more complexly branched processes.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 16-22, process length 15-19, number of processes 8-14. Number of specimens measured 10.

Material: 358 specimens.

Occurrence: Multiplicisphaeridium cladum was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area, the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole and the Brinkmarsh Formation of the Tortworth Inlier.

Multiplicisphaeridium cladum was first recorded from the Buildwas Formation of the Wenlock type area (Downie 1963); Mabillard & Aldridge (1985) recovered it from the Purple Shales and Buildwas Formation and Dorning (1981a) recovered it from the Purple Shales through to the Wenlock Limestone also in the type area (late Llandovery to late Wenlock).

It has been recovered from strata of similar age in Scotland (Dorning 1982), NE England (Barron 1989), the USA and Canada (Cramer 1970) and Austria (Priewalder 1987).

Multiplicisphaeridium fisherii (Cramer 1968) Lister 1970

(Pl. 19, figs. 8-10)

1968 *Baltisphaeridium fisherii* Cramer, p.65, pl.1, fig.1.

1970 *Baltisphaeridium fisherii* Cramer; Cramer, p.130, pl.7, figs. 116-118,122; pl.8, fig.138; pl.9, figs. 143,144; pl.10, fig.156; text-fig 39d.

1970 *Multiplicisphaeridium fisherii* (Cramer); Lister n. comb., p.89, pl.10, figs.11,18.

1973 *Multiplicisphaeridium fisherii* (Cramer) Lister; Eisenack *et al*., p.635.

Remarks

The diagnostic features of *Multiplicisphaeridium fisherii* are the heteromorphic processes; there is a variation on a single specimen between simple unbranched and distally tapering processes to processes that are branched (up to second order). *M. arbusculum* Dorning 1981a possesses more complexly branched processes (up to fourth order). The distinctive process types distinguish *M. fisherii* from any other described species of *Multiplicisphaeridium*.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 32-46, process length 36-52, number of processes 5-11. Number of specimens measured 8.

Material: 20 specimens.

Occurrence: *Multiplicisphaeridium fisherii* was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area (Sheinwoodian to Homerian). It has previously been recorded from lower Llandovery to lower Ludlow strata in the USA and Canada (Cramer 1968, 1970). In the Welsh

Borderlands it has been recorded from the Purple Shales through to the lower Elton Beds (late Llandovery to early Ludlow) by Hill (1974a,b) and by Dorning & Hill ('1991' in press).

Multiplicisphaeridium rasulii Dorning & Hill '1991' (in press)

(Pl. 19, fig. 7)

'1991' *Multiplicisphaeridium rasulii* Dorning & Hill, p.16, pl.1, fig.4.

Remarks

Observed specimens possess a spherical to subspherical vesicle and wide robust processes which branch distally (up to 3 orders). The number of processes (7-26) is more variable than is recorded in the original diagnosis (12-24). The processes are longer and more branched in *Multiplicisphaeridium arbusculum* Dorning 1981a and are shorter and stouter in *M. cladum* (Downie) Eisenack 1969 than in *M. rasulii*.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 14-22, process length 9-22, width of process base 3-4. Number of specimens measured 6.

Material: 6 specimens.

Occurrence: *Multiplicisphaeridium rasulii* was recovered from the Buildwas Formation of the Wenlock type area and the Woolhope Limestone of the Eastnor Park borehole (Sheinwoodian).

Dorning & Hill ('1991' in press) recorded *M. rasulii* from the Wych Beds of the Malverns (upper Llandovery).

Multiplicisphaeridium sp.A

(Pl. 20, figs. 1-3)

Description

Vesicle spherical to subspherical, vesicle surface faintly granulate, 6-10 long thin laevigate processes freely communicate with the vesicle and distally branch irregularly up to third order. Excystment is by a median split.

Remarks

The faintly granular surface combined with process type helps to distinguish this species of Multiplicisphaeridium from M. arbusculum Dorning 1981a, M. fisherii (Cramer) Lister 1970, M. cladum (Downie) Eisenack 1969, M. rasulii Dorning & Hill '1991' (in press) and other described species of Multiplicisphaeridium.

Dimensions: Populations from the Eastnor Park borehole and Tortworth Inlier (in microns): vesicle diameter 18-23, length of processes 17-29. Number of specimens measured 5.

Material: 5 specimens.

Occurrence: Multiplicisphaeridium sp.A was recorded from the Woolhope Limestone of the Eastnor Park borehole and the Brinkmarsh Formation of the Tortworth Inlier.

Genus Oppilatala Loeblich & Wicander 1976

Type species: by original designation Oppilatala vulgaris Loeblich & Wicander 1976.

Diagnosis: Refer to Loeblich & Wicander 1976, p.19.

Remarks

Oppilatala is similar to Multiplicisphaeridium Staplin 1961 but differs in having processes that are plugged proximally at the junction with the vesicle. It is most similar to Cymbosphaeridium Lister 1970 in having a double-layered vesicle wall and processes that do not communicate with the vesicle, the difference being that the cut off between vesicle and wall is typically straight in Cymbosphaeridium but is a tapering plug in Oppilatala. Cymbosphaeridium also excysted by means of a pylome whereas Oppilatala excysted by means of a median split. Also the processes of Oppilatala tend to be more complexly branched than those of Cymbosphaeridium and the processes of Oppilatala do not have the typical cauliflorate process terminations of Cymbosphaeridium.

Oppilatala eoplanktonica (Eisenack 1955a) Dorning 1981a emend.

(Pl. 20, figs. 4,6; Pl. 32, fig. 4)

1955a Hystrichosphaeridium eoplanktonicum Eisenack, pp.178-179, pl.IV, fig.14.

1959 Baltisphaeridium eoplanktonicum (Eisenack); Downie, pl.X, fig.3.

1963 Baltisphaeridium eoplanktonicum (Eisenack) Downie; Downie, p.643.

1968 Baltisphaeridium eoplanktonicum (Eisenack) Downie; Cramer, p.127.

1970 Baltisphaeridium eoplanktonicum (Eisenack) Downie; Cramer, pl.VIII ,figs. 129,131,134; text-fig. 39b.

1981a Oppilatala eoplanktonica (Eisenack); Dorning n. comb., p.196.

Emended diagnosis

The vesicle is spherical to subspherical, small, laevigate and possesses 3-4 processes which are 200-300% of the vesicle diameter in length. The processes are distally branched up to 3 orders, and are proximally constricted with a tapering plug.

Remarks

The few long processes distinguish Oppilatala eoplanktonica from O. smelrorii sp.nov. which has shorter more numerous processes. Oppilatala _ramusculosa_ (Deflandre) Dorning 1981a and _O. frondis_ (Cramer & Diez) Dorning 1981a possess a larger vesicle and shorter more numerous processes, _O. insolita_ (Cramer & Diez) Dorning 1981a possesses a larger vesicle with more numerous processes.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 16-27, process length 25-62. Number of specimens measured 10.

Material: 437 specimens.

Occurrence: _Oppilatala eoplanktonica_ was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area, the Woolhope Limestone of the Eastnor Park borehole and the Nant-ysgollon Shales of Central Wales (Sheinwoodian).

O. eoplanktonica was first recorded from the Baltic region (Eisenack 1955a), it has been recovered from Llandovery and Wenlock strata in the USA and Canada (Cramer 1968,1970) and from North Africa (Hill _et al_. 1985). In the Welsh Borderlands it has previously been recovered from the Purple Shales through to the Coalbrookdale Formation (late Llandovery to mid Wenlock) (Downie 1959,1963; Hill 1974a,b; Dorning 1981a).

Oppilatala frondis (Cramer & Diez 1972a) Dorning 1981a

(Pl. 20, fig. 5)

1972a _Baltisphaeridium frondis_ Cramer & Diez, p.152, pl.32, figs. 18, 19.

1973 _Multiplicisphaeridium frondis_ (Cramer & Diez); Eisenack _et al_. , p.645.

1978 _Multiplicisphaeridium frondis_ (Cramer & Diez); Kirjanov, p.71, pl.10, figs. 2,3,5.

1981a _Oppilatala frondis_ (Cramer & Diez); Dorning n. comb., p.196.

1987 Oppilatala ? frondis (Cramer & Diez) Dorning; Priewalder, p.47, pl.10, figs. 8-11.

1989 Oppilatala frondis (Cramer & Diez) Dorning; Barron, p.88, fig.4.

Remarks

Observed specimens possess fewer processes (14-18) than more typical specimens (20+) although the proximal plugging and distal branching of the processes (up to 3rd order) is characterisitic, as is the subspherical vesicle with a micrograpulate wall.

O. ramusculosa (Deflandre) Dorning 1981a has fewer more slender processes and a laevigate vesicle.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 30-47, process length 25-42. Number of specimens measured 8.

Material: 184 specimens.

Occurrence: Oppilatala frondis was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone of the Eastnor Park borehole.

O. frondis was first described from upper Llandovery strata in the USA (Cramer & Diez 1972a). It has also been recorded from Wenlock strata in the USSR (Kirjanov 1978) and NE England (Barron 1989) and from Llandovery and lower Wenlock strata in Austria (Priewalder 1987). Dorning (1981a) recovered O. frondis from the Purple Shales, Buildwas and lower Coalbrookdale formations of the Wenlock type area (late Llandovery to mid Wenlock).

Oppilatala insolita (Cramer & Diez 1972a) Dorning 1981a

(Pl. 20, fig. 8)

1972a Baltisphaeridium ramusculosum var. insolitum Cramer & Diez, p.155, pl.33, fig.36,37; pl.34, fig.38.

1981a *Oppilatala insolita* (Cramer & Diez); Dorning, p.196.

Remarks

Observed specimens typically have a relatively large laevigate vesicle and long branching processes. *Oppilatala frondis* (Cramer & Diez) Dorning 1981a is smaller with shorter processes and a micrograuulate vesicle. *O. ramusculosa* (Deflandre) Dorning 1981a has shorter processes which are more numerous.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 38-53, process length 39-61. Number of specimens measured 10.

Material: 71 specimens.

Occurrence: *Oppilatala insolita* was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area (Sheinwoodian to Homerian). It was first described from the upper Wenlock of the USA (Cramer & Diez 1972). Dorning (1981a) recovered it from the Wenlock Limestone through to the top of the Bringewood Beds (late Wenlock to mid Ludlow), he also records it from the Wenlock Limestone of Dudley in the West Midlands (Dorning 1983). Downie (1984) recorded its range in the British Isles as late Llandovery to mid Ludlow.

Oppilatala smelrorii sp.nov.

(Pl. 20, figs. 7,9,10)

1987 *Oppilatala* cf. *eoplanktonica* Smelror, p.150, pl.11, figs. 1,2.

Derivation of Name: named after Morten Smelror who first described and illustrated specimens that belong to this species.

Holotype: Plate 20, fig. 7 ;MPA 26059, F1, V38/2. BGS Lower Hill Farm Borehole, Shropshire (SO 5817 9788).

Diagnosis

The vesicle is spherical to subspherical and laevigate to microgranulate . There are 4-9 short processes which distally branch (up to 4 orders); the processes possess a proximal constriction. Excystment is by a median split.

Description

All processes possess the typical tapering constriction which cuts off the process from the vesicle, branching is normally confined to the distal half of the processes. The process length is variable from only 50% of vesicle diameter up to 150%.

Remarks

Oppilatala smelrorii sp.nov. has previously been included in O. eoplanktonica (Eisenack) Dorning 1981a. Downie (1959), in his description of specimens of O. eoplanktonica from the Coalbrookdale Formation of the Venlock type area, refers to a variation in process length and numbers which indicates inclusion of specimens referable to this new species; the illustration though is of a typical specimen of O. eoplanktonica. Smelror (1987) recovered specimens from strata in Norway which he compared with O. eoplanktonica but stated that the processes were more numerous and shorter than is typical; the illustrated specimens are very similar to O. smelrorii sp.nov.

Oppilatala ramusculosa (Deflandre) Dorning 1981a, O. frondis (Cramer & Diez) Dorning 1981a and O. insolita (Cramer & Diez) Dorning 1981a all have larger vesicles than O. smelrorii sp.nov. O. eoplanktonica (Eisenack) Dorning 1981a *sensu stricto* has fewer, longer processes.

Dimensions: Populations from the Venlock type area (in microns): vesicle diameter 16-32, process length 9-24. Number of specimens measured 11.

Material: 154 specimens.

Occurrence: Oppilatala smelrorii sp.nov. was recovered from the Buildwas and Coalbrookdale formations of the Venlock type area and from the Brinkmarsh Formation of the Tortworth Inlier (Sheinwoodian). Smelror (1986) recorded it from the Llandovery of Norway.

Oppilatala ramusculosa (Deflandre 1945) Dorning 1981a

(Pl. 20, figs. 11-12)

1942 Hystrichosphaeridium ramusculosum Deflandre, p.476, figs 2-6.

1945 Hystrichosphaeridium ramusculosum Deflandre; Deflandre, p.20, pl.1, figs. 8-16.

1959 Baltisphaeridium ramusculosum (Deflandre); Downie n. comb. p.59, pl.11, fig. 13.

1964 Baltisphaeridium ramusculosum (Deflandre) Downie; Cramer p.301, pl.3, figs. 3, 4-6,8,9.

1968 Baltisphaeridium ramusculosum (Deflandre) Downie; Martin p.61, pl.4: pp. 199-203; pl.5: p.222; pl.8, p.356,395.

1970 Multiplicisphaeridium ramusculosum (Deflandre); Lister n. comb., emend. p.92, pl.11, fig.8, 11-14; text-fig. 25a.

1973 Multiplicisphaeridium ramusculosum (Deflandre) Lister; Rauscher, p.177, pl.11, fig.23; pl.11, fig.24.

1974 Multiplicisphaeridium cf. ramusculosum (Deflandre) Lister; Riegel, p.37, pl.1, fig.4.

1976 Multiplicisphaeridium ramusculosum (Deflandre) Lister; Deunff, p.65, pl.11, fig.11; pl.13, fig.7; pl.14, fig.5.

1977 Multiplicisphaeridium ramusculosum (Deflandre) Lister; Playford, p.28, pl.11, figs. 14-20; text-fig. 16.

1981a Oppilatala ramusculosa (Deflandre); Dorning n. comb., p.196.

1987 Oppilatala ramusculosa (Deflandre) Dorning; Priewalder, p.48, pl.11,figs. 5,8. (with synonymy to 1985).

Remarks

Observed specimens typically possess a spherical laevigate vesicle and long slender distally branched processes (up to fourth order). Oppilatala frondis (Cramer & Diez 1972a) Dorning 1981a possesses shorter processes and a microgranulate vesicle.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 35-46, process length 35-50. Number of specimens measured 10.

Material: 76 specimens.

Occurrence: Oppilitala ramusculosa was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone of the Eastnor Park borehole (Sheinwoodian).

Oppilatala ramusculosa has a worldwide occurrence and ranges from the Upper Ordovician to the Middle Devonian. It has been recorded from Belgium (Martin 1968), France (Deunff et al. 1971; Rauscher 1973), Argentina (Pothe De Baldis 1975), Canada (Playford 1977), Greenland (Armstrong & Dorning 1984), Libya (Hill et al. 1985), USA (Wood & Clendening 1985) and Austria (Priewalder 1987). In the Welsh Borderlands Dorning 1981a recorded it from the mid Wenlock to the late Ludlow.

Genus *Salopidium* Dorning 1981a

Type Species: by original designation *Salopidium granuliferum* Dorning 1981a

Diagnosis: Refer to Dorning 1981a, p.198.

Remarks

Ammonidium Lister 1970 and *Percultisphaera* Lister 1970 have branched instead of simple processes; *Michrystridium* Deflandre 1937 has a laevigate vesicle in contrast to the granular vesicle of *Salopidium*.

Salopidium granuliferum (Downie 1959) Dorning 1981a

(Pl. 21, figs. 1-2)

1959 *Baltisphaeridium brevispinosum* var. *granuliferum* Downie, p.59, pl.10, fig.5.

1967 *Baltisphaeridium granuliferum* Downie; Martin, p.314, pl.1, fig.18.

1968 *Baltisphaeridium granuliferum* Downie; Martin, p.54, pl.4, figs. 204,208.

1970 *Baltisphaeridium granuliferum* Downie; Lister p.56, pl.2, figs. 2-5.

1973 *Baltisphaeridium granuliferum* Downie; Rauscher, p.177, pl.11, fig.19.

1981a *Salopidium granuliferum* (Downie); Dorning n. comb., p.198.

1982 *Salopidium granuliferum* (Downie) Dorning; Dorning, p.268, pl.2, fig.5.

1983 Salopidium granuliferum (Downie) Dorning; Dorning, p.33, pl.5, fig.7.

1984 Salopidium granuliferum (Downie) Dorning; Armstrong & Dorning, p.99, pl.1, fig.6.

1986 Salopidium granuliferum (Downie) Dorning; Smelror, pl.111, fig.11.

1987 Salopidium granuliferum (Downie) Dorning; Priewalder, p.51, pl.11, fig. 13,14; pl.12, figs. 1,2.

Remarks

Observed specimens characteristically possess a granular vesicle and numerous simple laevigate processes. Excystment is by a median split. Salopidium woolhopensis Dorning 1981a is larger with longer processes.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 22-36, process length 8-19. Number of specimens measured 10.

Material: 1122 specimens.

Occurrence: Salopidium granuliferum was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area, the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole, the Denbigh Grits of North Wales and the Dolyhir Limestone of the Old Radnor area. S. granuliferum has a previously recorded range of late Llandovery to early Ludlow, it has been recovered from strata in Belgium (Martin 1967, 1968), France (Rauscher 1973), Greenland (Armstrong & Dorning 1984), Norway (Smelror 1986), Austria (Priewalder 1987), and from Wales and the Welsh Borderlands (Downie 1959; Lister 1970; Hill 1974a,b; Dorning 1981a, 1982, 1983; Mabillard & Aldridge 1985).

Salopidium priewalderae sp.nov.

(Pl. 21, figs. 3-5)

1987 Salopidium ? sp.C Priewalder, p.52, pl.12, figs. 11-13; pl.18 fig.5.

Derivation of name: after Helga Priewalder who first informally described this species.

Holotype: Plate 21, fig. 3 ; VC/PS 3, F2, S49/2. Whitwell Coppice, Shropshire (SO 6194 0204).

Diagnosis

Vesicle spherical to subspherical, surface granulate; 26-70 regularly distributed processes, short, acuminate, and laevigate with proximally flaring bases. Excystment is by a median split.

Description

There is no overlapping of the process bases and therefore the central body is well defined. Distal tips of processes are darker and appear solid.

Remarks

Because of the rapidly tapering nature (distally) of the processes they tend to bend over one way preferentially and have the appearence of small horns. Salopidium granuliferum Dorning 1981a has longer broader processes. S. woolhopensis Dorning 1981a has fewer processes which are longer.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 25-39 (holotype 32), process length 2-7 (holotype 3-5). Number of specimens measured 10.

Material: 23 specimens.

Occurrence: Salopidium priewalderae sp.nov. was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and from the

Woolhope Limestone of the Eastnor Park borehole. Priewalder (1987) recorded it from the late Llandovery and early Wenlock of Austria.

Salopidium truncatum sp.nov.

(Pl. 21, figs. 7,8,10)

Derivation of name: from the Latin *truncus* meaning to cut short.

Holotype: Plate 21, fig. 10 ;MPA 26080, F1, L43/2. BGS Lower Hill Farm Borehole, Shropshire (SO 5817 9788).

Diagnosis

Vesicle spherical to subspherical possessing a granular surface. There are 16-30 regularly distributed processes with wide bases; the processes are slightly tapered and the distal extremity is expanded and truncated (evexate).

Description

The processes on a single specimen are homomorphic although there is a variation in the population from forms with smaller processes to those with longer ones. Some process bases overlap although most do not and therefore generally processes are discrete and the central body is well defined.

Remarks

Salopidium spatulispinosum Dorning & Hill '1991' (in press) possesses widened processes but does not have the truncated distal tips of Salopidium truncatum sp.nov.; also the greatest width of the processes is between proximal and distal ends in S. spatulispinosum while the greatest width is at the proximal end of the processes in S. truncatum sp.nov.

The process type also distinguishes S. truncatum sp.nov. from S. granuliferum (Downie) Dorning 1981a which has simply tapering processes and S. woolhopensis Dorning 1981a which has long simply tapering processes.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle diameter 22-34, process length 10-14. Number of specimens measured 10.

Material: 113 specimens.

Occurrence: *Salopidium truncatum* sp.nov. was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone of the Eastnor Park borehole.

Salopidium woolhopensis Dorning 1981a

(Pl. 21, fig. 14; Pl. 32, fig. 6; Pl. 35, figs. 3-4)

1981a *Salopidium woolhopensis* Dorning, p.198, pl.1, fig.14.

Remarks

Observed specimens of *S. woolhopensis* are generally smaller than more typical specimens but all possess a foveolate vesicle and long simple distally pointed processes. *S. granuliferum* (Downie) Dorning 1981a is smaller than *S. woolhopensis* and has wider more robust processes.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 28-43, process length 29-54. Number of specimens measured 10.

Material: 878 specimens.

Occurrence: *Salopidium woolhopensis* was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area, the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole and the Denbigh Grits of North Wales. Dorning (1981a) recovered it from the Buildwas and Coalbrookdale formations of the Wenlock type area.

Salopidium whitwellensis sp.nov.

(Pl. 21, figs. 6,9,11)

Derivation of Name: after Whitwell Coppice, the section from which this species was recovered.

Holotype: Plate 21, fig.6 ;WC/PS 5, F2, S41/3. Whitwell Coppice, Shropshire (SO 6194 0204).

Diagnosis

Vesicle spherical to subspherical, vesicle wall granulate with 300-500 small processes with expanded bases and rounded to bluntly pointed distal tips. Excystment is by a median split.

Description

The processes on a single specimen are homomorphic being of an equal length.

Remarks

The processes are so numerous that adjacent bases sometimes merge, although this can be a variable feature on a single specimen; overlapping of the process bases often means that the central bodies of observed specimens are not well defined. No other described species of *Salopidium* possesses as many processes as *Salopidium whitwellensis* sp.nov.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 19-27, process length <1. Number of specimens measured 10.

Material: 29 specimens.

Occurrence: *Salopidium whitwellensis* sp.nov. was recovered from the Coalbrookdale Formation of the Whitwell Coppice section.

Genus *Tunisphaeridium* Deunff & Evitt 1968

Type species: by original designation *Baltisphaeridium tentaculiferum* Martin 1966.

Diagnosis: Refer to Cramer 1970, p.192.

Remarks

Tunisphaeridium differs from all other described genera of acritarchs in possessing a membrane of filaments which interconnect the extremities of the radial processes.

Tunisphaeridium parvum Deunff & Evitt 1968

(Pl. 21, figs. 12-13; Pl. 22, fig. 1)

1968 *Tunisphaeridium parvum* Deunff & Evitt, pp.3-4, pl.2, figs. 15-18.

1970 *Tunisphaeridium parvum* Deunff & Evitt; Cramer, pp.192-194, pl.6, fig.111.

1972a *Tunisphaeridium parvum* Deunff & Evitt; Cramer & Diez, p.172.

1973 *Tunisphaeridium parvum* Deunff & Evitt; Eisenack *et al*. p.1055.

1973a *Tunisphaeridium parvum* Deunff & Evitt; Thusu, pl.2, fig.1.

Remarks

Tunisphaeridium parvum is distinguished by the generally uniform short numerous processes and the linking quasi-membraneous material in which delicate filaments can be seen in some specimens.

T. caudatum Deunff & Evitt 1968 in contrast possesses a small group of neighbouring processes which are conspicously longer than the rest.

Dimensions: Populations from the Venlock type area (in microns): vesicle diameter 27-36. Number of specimens measured 10.

Material: 37 specimens.

Occurrence: *Tunisphaeridium parvum* was recorded from the Buildwas and Coalbrookdale formations of the Venlock type area and the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole. *T. parvum* has previously been recorded from the Llandovery of the USA (Deunff & Evitt 1968; Cramer 1968, 1970; Cramer & Diez 1972a; Thusu 1973a). Dorning (1981a) recorded it from Llandovery to mid Ludlow strata in the Venlock and Ludlow type areas, he also recorded it from the Venlock Limestone of Dudley in the West Midlands. Hill (1974a,b) recorded it across the Llandovery/ Venlock boundary in the type area.

Tunisphaeridium tentaculiferum (Martin 1966) Cramer 1970

(Pl. 22, fig. 2)

1966 *Baltisphaeridium tentaculiferum* Martin, p.321, pl.1, fig.23.

1967 *Tunisphaeridium venosum* Cramer, p.235.

1968 *Tunisphaeridium venosum* Cramer; Cramer, p.66, pl.I, fig.5.

1968 *Tunisphaeridium concentricum* Deunff & Evitt, p.3, pl.I, figs. 1-12.

1970 *Tunisphaeridium tentaculiferum* (Martin); Cramer n. comb., p.192, pl.IV, figs. 105-109.

1972a *Tunisphaeridium tentaculiferum* (Martin) Cramer; Cramer & Diez, p.172.

1973 _Tunisphaeridium tentaculiferum_ (Martin) Cramer; Eisenack _et al_. pp. 1057-1059.

1973a _Tunisphaeridium tentaculiferum_ (Martin) Cramer; Thusu, pl.1, fig.30.

Remarks

The characteristic feature of _Tunisphaeridium tentaculiferum_ is the filamentous termination of the processes; there is a first order subdivision into 2-5 filaments and these can then further subdivide into 15 filaments or more; the level of subdivision is extremly variable. In contrast _T. parvum_ has a simple process termination.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle diameter 26-36, process length 10-15. Number of specimens measured 10.

Material: 50 specimens.

Occurrence: _Tunisphaeridium tentaculiferum_ was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole. It has previously been recovered from upper Llandovery and lower Wenlock strata in the USA (Evitt 1961; Cramer 1968, 1970; Deunff & Evitt 1968; Thusu 1973a), Belgium (Martin 1965, 1966), NW Spain (Cramer 1967) and Norway (Smelror 1986). In the Wenlock type area _T. tentaculiferum_ has been recovered from the Purple Shales and Buildwas Formation (late Llandovery to early Wenlock) (Dorning 1981a; Mabillard & Aldridge 1985). Hill (1974a,b) also recorded it from the type Llandovery area in Wales.

Genus _Tylotopalla_ Loeblich 1970.

Type species: by original designation _Tylotopalla digitifera_ Loeblich 1970.

Diagnosis: Refer to Loeblich 1970, p.737.

Remarks

Tylotopalla differs from *Diexallophasis* Loeblich 1970 in that the processes in the former are shorter, unbranched and less ornamented. *Estiastra* Eisenack 1959 has the central portion of its test formed from the bases of the processes, unlike *Tylotopalla* where the processes are differentiated from the circular to subcircular central body.

Tylotopalla caelamenicutis Loeblich 1970

(Pl. 22, figs. 4-6; Pl. 32, fig. 7)

1970 *Tylotopalla caelamenicutis* Loeblich, p.738, fig.33 A-C.

1972a *Lophosphaeridium agudisimum* Cramer & Diez, p.166, pl.35, figs. 56,57.

1973 *Tylotopalla caelamenicutis* Loeblich; Eisenack *et al*. p.1063-1064.

1986 *Tylotopalla* cf. *caelamenicutis* Loeblich; Smelror, p.151, pl.IV, fig.1.

1987 *Tylotopalla caelamenicutis* Loeblich; Molyneux, pp. 306-307, figs 4a-d, 5a-c.

1989 *Tylotopalla caelamenicutis* Loeblich; Martin, fig.151, C.

Remarks

Observed specimens are characterized by a subspherical microgranulate vesicle with more than 20 low conical processes with striations around their bases and a diagnostic notch near their distal terminations.

Tylotopalla robustispinosa (Downie) Eisenack *et al*. 1973 has fewer generally longer processes.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 22-25, length of processes 2-3. Number of specimens measured 10.

Material: 78 specimens.

Occurrence: *Tylotopalla caelamenicutis* was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone of the Eastnor Park borehole. It has previously been recovered from the late Llandovery of the USA (Loeblich 1970; Cramer & Diez 1972a) and Norway (Smelror 1986).

In the Welsh Borderlands *T. caelamenicutis* has previously been recovered from the Purple Shales, Buildwas and lower Coalbrookdale formations (Dorning 1981a). It has also been recovered from lower Wenlock strata in Scotland (Molyneux 1987).

Tylotopalla cf. *cellonensis* Priewalder 1987

(Pl. 22, figs. 7,9)

cf. 1987 *Tylotopalla cellonensis* Priewalder, p.54, pl.13, figs. 9-12; text-fig. 25.

cf. 1989 *Tylotopalla cellonensis* Priewalder; Barron, p.90, fig. 4f.

Remarks

The vesicle is spherical to subspherical, possessing regularly distributed processes which are sharp tipped, the distal terminations being a simple point or a notched bifurcation. The edges of the processes are typically jagged or prickly giving the surface of the processes a granulate appearance. The central vesicle is also granulate. On observed specimens the number of processes is generally less (6-10) than on typical specimens of *T. cellonensis*.

Tylotopalla robustispinosa (Downie 1959) Eisenack *et al*. 1973 possesses broader and shorter processes which are less ornamented. *T. caelamenicutis* Loeblich 1969 has more processes that are shorter in length.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 23-33, process length 7-15. Number of specimens measured 8.

Material: 14 specimens.

Occurrence: *Tylotopalla* cf. *cellonensis* was recovered from the Buildwas and lower Coalbrookdale formations of the Wenlock type area.

Priewalder (1987) first described it from the Llandovery and early Wenlock of Austria. Barron (1989) recovered it from sediments of a questionable mid-Wenlock age in the Cheviot Hills, NE England.

Tylotopalla robustispinosa (Downie 1959) Eisenack *et al*. 1973

(Pl. 22, fig. 8; Pl. 33, fig. 4 ; Pl. 35, fig. 6)

1959 *Baltisphaeridium robustispinosum* Downie, p.61, pl.10, fig.7.

1963 *Baltisphaeridium robustispinosum* Downie; Downie, p.641.

1963 *Baltisphaeridium robustispinosum* Downie; Downie & Sarjeant, p.90.

1964 *Baltisphaeridium robustispinosum* Downie; Downie & Sarjeant, p.95.

1967 *Baltisphaeridium robustispinosum* Downie; Lister & Downie, p.171.

1970 *Baltisphaeridium robustispinosum* Downie; Cramer, pp.186-187, fig.60c.

1973 *Tylotopalla robustispinosa* (Downie 1959); Eisenack *et al*. n. comb., p.1071-1072.

1987 *Tylotopalla* aff. *robustispinosa* (Downie 1959) Eisenack *et al*.; Molyneux p.308, figs. 4e,f;6a.

Remarks

Specimens possess a granulate spherical vesicle which has 6-12 stout irregular conical processes ending in a sharp thin tip or a rounded digitate tip. Processes typically bear a low ornament of grana and echinae.

Tylotopalla caelamenicutis has more processes all of which are shorter. *T. cellonensis* has a more jagged outline to the processes which are sharp tipped, it also has a better-developed ornament on the vesicle.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 23-35, process length 5-91, width of process at base 3-4. Number of specimens measured 10.

Material: 727 specimens.

Occurrence: *Tylotopalla robustispinosa* was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area, the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole, and the Denbigh Grits and Lower Nantglyn Flags of North Wales.

T. robustispinosa has previously been recovered from the Buildwas and Coalbrookdale formations and lower Wenlock Limestone of the Welsh Borderlands (Downie 1959,1963; Downie & Sarjeant 1963,1964; Lister & Downie 1967; Lister 1970; Dorning 1981a,1983). Molyneux (1987) recovered *T.* aff. *robustispinosa* from lower Wenlock strata in Scotland.

Tylotopalla wenlockia Dorning 1981a

(Pl. 22, fig. 10; Pl. 32, fig. 9; Pl. 33, fig. 1; Pl. 36, figs. 1-2)

1981a *Tylotopalla wenlockia* Dorning, p.200, pl.II, fig.4.

1987 *Tylotopalla wenlockia* Dorning; Molyneux, p.309, figs. 4g-i; 6b-d.

1989 *Tylotopalla wenlockia* Dorning; Barron, p.90, figs. 5 B,C.

Remarks

Observed specimens possess a subspherical vesicle which is laevigate to micrgranulate; there are 8-15 long, granular to echinate processes which are tubular for about 3/4 of their length and then taper to a simple tip. Tylotopalla robustispinosa (Downie) Eisenack et al. 1973 in contrast has short processes. T. wenlockia is no doubt an end member of a T. robustispinosa group, but because there appears to be a polar split of process lengths with few if any gradational forms, a specific split is sensible even though both morphology (apart from process length) and stratigraphical range are very similar.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 23-33, process length 15-28, width of process at base 3-4. Number of specimens measured 8.

Material: 21 specimens.

Occurrence: Tylotopalla wenlockia was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole.

T. wenlockia has previously been recorded from the Buildwas Formation through to the Elton Beds (Wenlock to early Ludlow) in the Wenlock type area (Dorning 1981a, 1983) it has also been recorded from lower Wenlock strata in Scotland (Molyneux 1987) and Wenlock or possibly lower Ludlow Strata in Greenland (Armstrong & Dorning 1984).

Genus *Visbysphaera* Lister 1970

Type Species: by original designation *Baltisphaeridium dilatispinosum* Downie 1963.

Diagnosis: Refer to Lister 1970, p.98.

Remarks

Visbysphaera is characterized by its double walled vesicle and heteromorphic processes. There is possible confusion of *Visbysphaera* with *Gorgonisphaeridium* Staplin *et al*. 1965, but the latter possesses solid rather than hollow processes and has a single rather than double walled vesicle; processes on *Gorgonisphaeridium* are also generally homomorphic rather than heteromorphic.

Visbysphaera dilatispinosa (Downie 1963) Lister 1970

(Pl. 22, figs. 12-14)

1963 *Baltisphaeridium dilatispinosum* Downie, p.642, pl.92, fig.4.

1966a *Baltisphaeridium dilatispinosum* Downie; Cramer, p.35, pl.4 fig.1.

1968 *Baltisphaeridium dilatispinosum* Downie; Jardiné & Yapaudjian, pl.3, fig.13.

1968 *Baltisphaeridium dilatispinosum* Downie; Martin, p.50, pl.3, figs. 137,138; pl.8, figs. 378,379, text-fig.7.

1970 *Visbysphaera dilatispinosa* (Downie); Lister n. comb., p.98, pl.13, fig.16; text-fig. 19j,27f.

1973 Multiplicisphaeridium dilatispinosum (Downie); Eisenack et al. n. comb., p.611.

1986 Visbysphaera dilatispinosa (Downie) Lister; Smelror, pl.IV, fig.10.

Remarks

A very distinctive species possessing a laevigate, subspherical, double walled vesicle and short, transparent, distally inflated processes which have numerous small spines on their distal surface.

The process type distinguishes Visbysphaera dilatispinosa from all other described species of Visbysphaera.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle diameter 48-57, process length 10-14, width of process at base 2-8, maximum width of process 3-12. Number of specimens measured 10.

Material: 76 specimens.

Occurrence: Visbysphaera dilatispinosa was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area, the Dolyhir Limestone of the Old Radnor area and the Brinkmarsh Formation of the Tortworth Inlier.

Visbysphaera dilatispinosa has been recorded from the Ludlow of NW Spain (Cramer 1966a) and Belgium (Martin 1968), from the late Ludlow of the Sahara (Jardiné & Yapaudjian 1968), from the Wenlock of the USA (Thusu 1973 a,b) and from the Llandovery of Norway (Smelror 1986). Downie (1963) obtained it from the Buildwas Formation of the Wenlock type area and Lister (1970) recorded it from the Wenlock Limestone, Lower Elton Beds and the Whitcliffe Beds (late Wenlock to late Ludlow) of the Welsh Borderlands. It has also been recorded from the Wenlock Limestone of Dudley in the West Midlands (Eisenack 1977, Dorning 1983). Downie (1984) and Dorning (1981a) indicate its stratigraphical range in Britain as being late Llandovery to early Ludlow, although Lister (1970) found sporadic specimens in the Whitcliffe Beds and the range is likely to extend up to the late Ludlow.

Visbysphaera cf. dudleyspinosa Dorning & Hill '1991' (in press)

(Pl. 22, fig. 11; Pl. 23, fig. 1)

cf. '1991' Visbysphaera dudleyspinosa Dorning & Hill, p.21, pl.3, fig.11.

Remarks

Observed specimens possess a subspherical vesicle and numerous, relatively long processes that branch distally (up to two orders). The specimens recovered are smaller than those recorded by Dorning & Hill ('1991'). Excystment is by a split in the vesicle wall.

Visbysphaera meson (Eisenack) Lister 1970 is larger. Visbysphaera gotlandica (Eisenack) Lister 1970 possesses smaller but wider processes.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 22-33, process length 4-7. Number of specimens measured 10.

Material: 83 specimens.

Occurrence: Visbysphaera cf. dudleyspinosa was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area (Sheinwoodian to Homerian).

Dorning and Hill ('1991') recorded V. dudleyspinosa from the Coalbrookdale Formation of Wrens Nest in the West Midlands.

Visbysphaera gotlandica (Eisenack 1954) Lister 1970

(Pl. 23, figs. 2,3,7)

1954 Hystrichosphaeridium gotlandicum Eisenack, p.209, pl.1, fig.5, text-fig.6.

1963 Baltisphaeridium gotlandicum (Eisenack); Downie & Sarjeant n. comb., p.90.

1965 *Baltisphaeridium gotlandicum* (Eisenack) Downie & Sarjeant; Eisenack, p.261.

1967 *Baltisphaeridium peltatum* (Eisenack); Cramer, p.246, pl.1, fig.6.

1970 *Baltisphaeridium gotlandicum* (Eisenack) Downie & Sarjeant; Cramer p.157, pl.16, figs. pl.16, figs. 224,231,235, text-fig. 47m.

1970 *Visbysphaera gotlandica* (Eisenack); Lister n. comb., p.98.

1973 *Multiplicisphaeridium gotlandicum* (Eisenack); Eisenack *et al*. n. comb., p.651.

1978 *Multiplicisphaeridium gotlandicum* (Eisenack) Eisenack; Eisenack, p.287, fig.17.

1978 *Visbysphaera gotlandica* (Eisenack) Lister; Kirjanov, p.87, pl.11, figs. 2,3.

1985 *Visbysphaera gotlandica* (Eisenack) Lister; Hill *et al*., p.27, pl.11, fig.10.

1987 *Visbysphaera gotlandica* (Eisenack) Lister; Priewalder., p.61-62, pl.15, figs.9,10,13; pl.20, figs.5,6; pl.21, fig.1; text-fig. 33.

Remarks

Specimens are characterized by a spherical vesicle and about 30 regularly distributed processes. The processes are short, baculate, distally thickened and show palmate branching.

Visbysphaera meson (Eisenack) Lister 1970, in contrast, possesses generally longer, more irregular processes; *V. oligofurcata* (Eisenack) Lister 1970 has long, spikey processes.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle diameter 40-48, process length 3-5. Number of specimens measured 10.

Material: 58 specimens.

Occurrence: *Visbysphaera gotlandica* was recorded from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone and Coalbrookdale formations of the Eastnor Park borehole.

It has previously been recovered from the upper Llandovery of Gotland (Eisenack 1954, 1965), the upper Llandovery and Wenlock of NW Spain (Cramer 1967), the upper Llandovery and Wenlock of the USA and Canada (Cramer 1970; Cramer & Diez 1972a), the Wenlock of the USSR (Kirjanov 1978), the Llandovery of the Sahara (Hill *et al*. 1985) and the Llandovery of Austria (Priewalder 1987). Downie (1984) and Dorning (1981a) record its stratigraphical range in Britain as mid Llandovery to late Wenlock.

Visbysphaera meson (Eisenack 1954) Lister 1970

(Pl. 23, figs. 4-6; Pl. 33, figs. 2-3)

1954 *Hystrichosphaeridium intermedium* Eisenack, p.208, pl.1, figs.3,9; text-fig. 3,4.

1955a *Hystrichosphaeridium meson* Eisenack, p.179.

1959 *Baltisphaeridium* cf. *meson* (Eisenack); Downie n. comb., p.60, pl.10, fig.8.

1965 *Baltisphaeridium meson* (Eisenack) Downie; Eisenack, p.261, pl.22, fig.12.

1970 *Baltisphaeridium meson* (Eisenack) Downie; Cramer, p.154, pl.17, fig.239; text-fig. 46c.

1970 Visbysphaera meson (Eisenack); Lister n. comb., p. 100.

1973 Multiplicisphaeridium meson (Eisenack); Eisenack et al. n. comb. , p.681.

1978 Multiplicisphaeridium meson var. meson (Eisenack); Kirjanov, p.73, pl.11, fig.5.

1979 Multiplicisphaeridium meson (Eisenack) Eisenack; Cramer et al., p.44.

1987 Visbysphaera meson (Eisenack) Lister; Priewalder, p.62, pl.16, fig.1; text-fig. 34.

Remarks

Specimens have heteromorphic processes. On any single specimen, the processes may be wide or thin, and have simple, bifurcate or trifurcate distal terminations.

Visbysphaera gotlandica (Eisenack) Lister 1970 possesses generally, shorter, less irregular processes; V. microspinosa (Eisenack) Lister 1970 has an ornament of thin spines rather than processes.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 42-59, length of processes 5-12. Number of specimens measured 10.

Material: 142 specimens.

Occurrence: Visbysphaera meson was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area, the Woolhope Limestone of the Eastnor Park borehole and the Nant-ysgollon Shales of Central Wales.

It has previously been recorded from upper Llandovery strata in Gotland (Eisenack 1954, 1965), Sweden (Schultz 1968; Cramer 1970), the USA and Canada (Cramer 1970; Cramer & Diez 1972a), Austria (Priewalder 1987) and the Venlock of the USSR (Kirjanov 1978). In the Welsh Borderlands it has been recorded from strata of late Llandovery to late Ludlow age (Downie 1959, 1963, 1984; Lister 1970; Dorning 1981a).

Visbysphaera filosa sp. nov.

(Pl. 23, figs. 8-11)

Derivation of Name: From the Latin *Filum* meaning a thread.

Diagnosis

Vesicle spherical to subspherical and double walled, processes are short, numerous (40-70), thin, filamentous and sinuous, possessing bifurcating and trifurcating distal tips. Excystment is by a median split.

Description

The outer wall of the vesicle is thick giving it a dark body colour. Processes are hollow and are sealed off from the vesicle cavity by a proximal plug, they are discrete but numerous and cover the whole of the vesicle.

Remarks

The numerous and thin filamentous processes distinguish Visbysphaera filosa sp. nov. from all other described species of Visbysphaera. Lophosphaeridium microspinosum (Eisenack) Downie 1963 possesses homomorphic, simple, solid processes and a single walled vesicle.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle diameter 48-65, process length 4-7, process width <1. Number of specimens measured 10.

Material: 78 specimens.

Occurrence: Visbysphaera filosa sp. nov. was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone of the Eastnor Park borehole.

Visbysphaera oligofurcata (Eisenack 1954) Lister 1970

(Pl. 23, fig. 12; Pl. 24, fig. 1; Pl. 36, figs. 3-4)

1954 *Hystrichosphaeridium oligofurcatum* Eisenack, p.208, pl.1, fig.4; text-fig. 5.

1963 *Baltisphaeridium oligofurcatum* (Eisenack); Downie & Sarjeant n. comb., p.90.

1964 *Baltisphaeridium oligofurcatum* (Eisenack) Downie & Sarjeant; Cramer, p.300, pl.7, fig.2; text-fig.1.

1970 *Baltisphaeridium oligofurcatum* (Eisenack) Downie & Sarjeant; Cramer, p.155, pl.16, figs. 227, 228, 230; text-fig. 46g.

1970 *Visbysphaera oligofurcata* (Eisenack); Lister n. comb., p.100, pl.13, figs. 14,15; text-fig. 19k.

1973 *Multiplicisphaeridium oligofurcatum* (Eisenack); Eisenack *et al*. n. comb., p.703.

1979 *Multiplicisphaeridium oligofurcatum* (Eisenack) Eisenack *et al*.; Cramer *et al*., p.44.

1987 *Visbysphaera* cf. *oligofurcata* (Eisenack) Lister; Priewalder, pp.63-64, pl.15, fig.8; text-fig.35.

Remarks

Observed specimens are characterised by a dark, laevigate, spherical vesicle and numerous, long, regularly distributed, spikey processes which are either simple or which bifurcate once; all end in a sharp tip.

Visbysphaera meson (Eisenack) Lister 1970 in contrast has more distinctly heteromorphic processes which are stouter and shorter. *V. gotlandica* (Eisenack) Lister 1970 possesses shorter processes which are distally thickened and branched.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle diameter 48-59, process length 7-13. Number of specimens measured 10.

Material: 13 specimens.

Occurrence: *Visbysphaera oligofurcata* was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone of the Eastnor Park borehole. It has previously been recovered from the upper Llandovery of Gotland (Eisenack 1954, 1965; Cramer 1970), the Ludlow of Northern Spain (Cramer 1964, 1970), the upper Llandovery and Wenlock of the USA and Canada (Cramer 1970; Cramer & Diez 1972a), the upper Llandovery and lower Wenlock of Norway (Smelror 1986) and the upper Llandovery of Austria (Priewalder 1987). In the Welsh Borderlands it has previously been recovered from strata of late Llandovery to late Ludlow age (Downie 1963; Lister 1970; Hill 1974; Dorning 1981a).

Visbysphaera varispinosa Dorning & Hill '1991' (in press)

(Pl. 24, figs. 2-4)

1973a *Visbysphaera dilatispinosa* var. A Thusu, p.141, pl.2, figs. 2,3.

'1991' *Visbysphaera varispinosa* Dorning & Hill, p.23, pl.3, fig.4.

Remarks

Observed specimens possess a spherical to subspherical, thick walled vesicle. Two types of process predominate; more numerous, thin, cylindrical processes with bifurcate or trifurcate distal terminations; and less common, distally inflated processes with a single terminal spine.

Visbysphaera dilatispinosa (Downie) Lister 1970 possesses only inflated processes; *V. meson* has heteromorphic processes but none are inflated.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 35-46, length of cylindrical processes 3-5, length of inflated processes 4-7, width of cylindrical processes <1, width of inflated processes 3-6. Number of specimens measured 4.

Material: 4 specimens.

Occurrence: *Visbysphaera varispinosa* was recovered from the Coalbrookdale Formation of Whitwell Coppice. Thusu (1973a) recovered specimens which look very similar to *V. varispinosa* from Wenlock strata in New York state (USA); Dorning & Hill ('1991') recovered *V. varispinosa* from the Whitcliffe Beds (upper Ludlow) of Shropshire.

Visbysphaera sp.A

(Pl. 24, figs. 5-6)

Description

Vesicle subspherical, laevigate to scabrate and double walled. There are 12-15 regularly distributed, cylindrical and hollow processes which are, distally bifurcate or trifurcate. The processes are a maximum of 50% of the vesicle diameter in length.

Remarks

The vesicle is dark in colour, in contrast to the lighter coloured hollow processes. The length and cylindrical style of the processes distinguish this species from other described species of *Visbysphaera*.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 38-47, process length 18-22. Number of specimens measured 3.

Material: 3 specimens.

Occurrence: *Visbysphaera* sp.A. was recovered from the Coalbrookdale Formation of the Wenlock type area.

Subgroup *Polygonomorphitae* Downie, Evitt & Sarjeant, 1963.

Genus *Fractoricoronula* Colbath 1979 emend. Turner 1984

Type species: by original designation *Fractoricoronula cubitalia* Colbath 1979.

Diagnosis: Refer to Turner 1984, p. 111.

Remarks: This genus differs from *Veryhachium* Deunff 1954 ex Downie 1959 in that its processes have solid proximal plugs and do not widen gradually toward the base to finally merge imperceptibly with the vesicle as do processes of typical representatives of *Veryhachium*. In *Fractoricoronula*, the slender processes are cylindrical or nearly so until just below the basal plug. Then they expand directly into the vesicle wall.

Fractoricoronula checkleyensis (Dorning 1981a) n.comb.

(Pl. 25, figs. 8-9)

1981a *Veryhachium checkleyensis* Dorning, p.200, pl.1, fig. 10.

1985 ?*Dateriocradus monterrosae* (Cramer) Dorning; Hill *et al*. pl. 9, fig. 11.

Emended diagnosis

Vesicle subtriangular, inflated and laevigate to microgranulate, there are three long, laevigate to microgranulate processes which proximally are constricted by tapering plugs extending up to a quarter of the way up the process. The processes are mainly hollow, simple and acuminate.

Description

The processes may possess a granulate ornament which when present is more obvious at their proximal ends, around the connection with the vesicle. The processes are over twice the vesicle diameter in length, they are parallel-sided or nearly so for much of their length, flaring rapidly to merge with the vesicle wall just below the basal plug.

Remarks

In the original diagnosis (Dorning 1981a, p.200) it is stated that 'the vesicle and proximal quarter of the processes are distinctly darker (? thicker) than the rest of the processes'; this is due to plugging or constriction proximally in the processes. It is probable that the vesicle is two walled with the outer layer forming the processes.

Fractoricornula cubitalia Colbath 1979 possesses four processes instead of three, and F. trihetica Turner 1984 is larger than F. checkleyensis. The proximal plugging of the processes distinguishes F. checkleyensis from any described species of Veryhachium.

Dimensions: Population from the Venlock type area (in microns): length across one side 20-25, length of processes 48-65. Number of specimens measured 10.

Material: 54 specimens.

Occurrence: Fractoricoronula checkleyensis was recovered from the Buildwas and Coalbrookdale formations of the Venlock type area and the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole (Telychian to Sheinwoodian).

Dorning 1981a recorded F. checkleyensis from the Woolhope Limestone of Herefordshire and the Buildwas and Coalbrookdale formations of the Venlock type area. Hill 1985 (pl.9, fig. 11) illustrates a similar specimen to E. checkleyensis from the Llandovery of Libya. Dorning & Hill '1991' (in press) use the appearence of E. checkleyensis to help define the Cymatiosphaera pavimenta Biozone, formally named in Dorning & Bell 1987 and equivalent to the zone W2 of Dorning 1981a. Its range in Britain can possibly be extended into the late Llandovery, as it was recovered from the lowermost Woolhope Limestone of the Eastnor Park borehole (which is probably of Telychian age).

Genus Onondagaella (Deunff 1955) Cramer 1966c

Type species: by original designation Veryhachium asymmetricum Deunff 1955

Diagnosis: Refer to Cramer 1966c, pp. 86-87.

Remarks

Onondagaella has a triangular vesicle with three processes, one at each corner. Two of the processes are similar in form and size, but the third is generally thicker and shorter. Excystment is by a cyclopyle which is closed by a thickened, subspherical or hemispherical plug (an epibystra).

Pulvinosphaeridium Eisenack 1954 is larger and has generally more numerous homomorphic processes.

Onondagaella cf. asymmetrica (Deunff 1955) Cramer 1966c emend. Playford 1977.

(Pl. 25, figs. 3,5)

cf. 1955 Veryhachium asymmetricum Deunff, pl.1., fig.2.

cf. 1961 Veryhachium asymmetricum Deunff; Deunff, p.216.

cf. 1966c Onondagella asymmetrica (Deunff); Cramer n. comb., p.87, text-fig. 2-15.

cf. 1970 Onondagaella asymmetrica (Deunff) Cramer; Cramer, pl.31, fig.10.

cf. 1977 Onondagaella sp. (Deunff); Swanson & Dorning, pl.1, fig.4.

cf. 1977 Onondagaella asymmetrica (Deunff) Cramer; Playford, p. 30, pl. 12, figs. 13-16; pl. 13, figs 10,11.

Remarks

Onondagaella cf. asymmetrica is smaller than O. asymmetrica *sensu stricto* and possesses thinner and sharper tipped processes than O. deunffi Cramer 1966c.

Dimensions: Populations from the Venlock type area (in microns): maximum width 41-53. Number of specimens measured 11.

Material: 80 specimens.

Occurrence: Onondagaella cf. asymmetrica was recovered from the Coalbrookdale Formation of the Venlock type area and the Woolhope Limestone of the Eastnor Park borehole.

It was first recovered from the sediment-infilling of a tabulate coral collected in Ontario from Middle, or possibly Lower Devonian strata (Deunff, 1954, 1955, 1961, 1966). Subsequently, Jardiné & Yapaudjian (1968), Jardiné (1972) and Jardiné et al. (1974) have reported the species from Lower Devonian (Upper Siegenian-Eifelian) and possibly older (Ludlow-Gedinnian) sediments of the Algerian Sahara. Cramer (1972) recovered O. asymmetrica in low numbers (less than 1% of the assemblage) throughout Silurian strata in North America. Swanson & Dorning (1977) recovered a specimen which bears a resemblance to O. asymmetrica from the late Ludlow of North Wales.

Genus Pulvinosphaeridium Eisenack 1954 emend. Deunff 1954

Type species: by original designation Pulvinosphaeridium pulvinellum Eisenack 1954.

Diagnosis: Refer to Deunff 1954, pp.305-306.

Remarks: Pulvinosphaeridium possesses large rounded processes which have gradually confluent bases, while Estiastra Eisenack 1959 possesses pointed processes, with process bases that form acute angles with each other.

Pulvinosphaeridium cf. oligospinosum (Eisenack 1934) Eisenack 1954

(Pl. 25, fig. 4)

cf. 1934 Ovum hispidium oligospinosum Eisenack, pp. 64,65, pl.4, figs. 15-18.

cf. 1954 Pulvinosphaeridium oligospinosum (Eisenack); Eisenack n. comb. , p.210.

cf. 1954 Pulvinosphaeridium oligospinosum (Eisenack) Eisenack; Deunff, p.306.

cf. 1964 Veryhacium oligospinosum (Eisenack); Downie & Sarjeant, p.152.

cf. 1970 Pulvinosphaeridium oligospinosum (Eisenack) Eisenack; Cramer, p.116, pl.xx,, figs. 301, 303-305, text-fig. 34c.

Remarks

The observed specimen possesses three large broadly rounded processes that possess solid pointed tips. The central portion of the vesicle is formed through confluence of the process bases. Pulvinosphaeridium oligospinosum *sensu stricto* possesses more processes (four to six).

Dimensions: Specimen from the Eastnor Park borehole (in microns): total vesicle diameter 250.

Material: 1 specimen.

Occurrence: *Pulvinosphaeridium* cf. *oligospinosum* was recovered from the Woolhope Limestone of the Eastnor Park borehole. *Pulvinosphaeridium oligospinosum* has previously been recovered from the upper Llandovery of Gotland (Eisenack 1934, 1938, 1954) and Canada (Cramer 1970).

Pulvinosphaeridium pulvinellum Eisenack 1954

(Pl. 25, fig. 7)

1954 *Pulvinosphaeridium pulvinellum* Eisenack, p.210, pl.1, fig.10.

1959 *Pulvinosphaeridium oligoprojectum* Downie, p.64, pl.10, fig.12, pl.12, fig.12.

1964 *Pulvinosphaeridium pulvinellum* Eisenack; Downie & Sarjeant, p.143

1966 *Pulvinosphaeridium pulvinellum* Eisenack; Martin, p.318, pl.1, fig. 26.

1970 *Pulvinosphaeridium pulvinellum* Eisenack; Cramer, pp.116-117, fig.34a.

1973 *Pulvinosphaeridium pulvinellum* Eisenack; Eisenack *et al.*, p.1041.

Remarks

Observed specimens have five broad, laevigate, hollow and rounded processes which unite to form an ill-defined body. *P. oligospinosum* (Eisenack) Eisenack 1954 is distinguished by secondary thickenings in the distal portions of the processes. *Estriastra granulata* Downie 1963 possesses more processes which are ornamented, the processes bases unite proximally to form acute angles; in *P. pulvinellum* the process bases are confluent.

Dimensions: Populations from the Wenlock type area (in microns): total vesicle diameter 156-172. Number of specimens measured 7.

Material: 10 specimens.

Occurrence: Pulvinosphaeridium pulvinellum was recovered from the Coalbrookdale Formation of the Wenlock type area and the Woolhope Limestone of the Eastnor Park borehole. First recorded from the late Llandovery of Gotland (Eisenack 1954), it has been obtained subsequently from Llandovery and Wenlock sediments in Belgium (Martin 1966), and Canada (Cramer 1970).

In the Welsh Borderlands P. pulvinellum has previously been recovered from the upper Llandovery to the upper Wenlock (Purple Shales to the Wenlock Limestone) (Downie 1959; Dorning 1981a, Dorning 1983).

Genus Veryhachium Deunff *ex* Downie 1959

Type species: by original designation Hystrichosphaeridium trisculum Deunff 1954.

Remarks

Veryhachium is characterised by a hollow, triangular to polygonal vesicle, with corners ('angles') smoothly extended as hollow tapering processes that terminate with simple acuminate distal extremities and have unobstructed internal communication with the vesicle cavity. Processes usually number between three and eight per vesicle. Vesicle and process walls are laevigate to granulate. Excystment is by an epityche.

Fractoricornula Turner 1984 possesses proximal plugs in the processes; Dateriocradus Tappan & Loeblich 1971 possesses multifurcate processes

Veryhachium lairdii (Deflandre 1946) Deunff 1959 ex Downie 1959

(Pl. 25, fig. 13; Pl. 26, fig. 2)

nom. nud. 1946 Hystrichosphaeridium lairdi Deflandre, p.1112, 2 figs.

1959 Veryhachium lairdii (Deflandre); Deunff n. comb., p.28, pl.8, figs. 75-79

1987 Veryhachium lairdii (Deflandre) Deunff; Priewalder, pp. 57-58, pl.7, fig.1. (with synonymy to 1985).

Remarks

The vesicle is square with four, hollow, sharp-tipped processes, one situated at each corner, occasionally a fifth process arises from the centre of the vesicle. Forms with both straight and concave sides to the vesicle are here included in V. lairdii.

Veryhachium rhomboidium Downie 1959 has 4 to 6 longer processes.

Dimensions: Populations from the Venlock type area (in microns): maximum vesicle width 12-25, length of processes 15-20. Number of specimens measured 5.

Material: 5 specimens.

Occurrence: Veryhachium lairdii was recovered from the Buildwas Formation of the Venlock type area (Sheinwoodian).

V. lairdii is a long ranging taxon occurring in strata of early Ordovician to early Permian age. It has been recovered from the Caradoc to the Ashgill of Canada (Legault 1982; Jacobson & Achab 1985), the upper Llandovery of New York, USA (Miller & Eames 1982), the Caradoc, Ashgill, Llandovery and Givetian of Libya (Molyneux & Paris 1985; Hill et al. 1985; Moreau-Benoit 1984), the Arenig of Sardinia (Albani, Di Milia et al. 1985) the upper Llandovery of NW Spain (Cramer 1964) and the upper Ludlow of Austria (Priewalder 1987). Dorning (1981a) recorded it from upper Llandovery and lower Venlock strata in the Venlock type area.

Veryhachium rhomboidium Downie 1959 emend. Turner 1984

(Pl. 25, fig. 12)

1959 Veryhachium rhomboidium Downie, p. 62, pl. 12, fig. 10.

1960 Veryhachium rhomboidium Downie; Stockmans & Willière, p. 2, pl. 1, fig. 9; pl. 2, fig. 23.

1963 *Veryhachium rhomboidium* Downie; Wall & Downie, p. 781, pl. 113, figs. 9-12, pl. 114, fig. 1-3; text-figs. 1, a-e.

1963 *Veryhachium rhomboidium* Downie; Downie, p. 636.

1969 *Veryhachium rhomboidium* Downie; Martin, p. 101, pl. 8, fig. 373; text-fig. 49.

1970 *Veryhachium trapezionarion* Downie; Loeblich, p. 743, fig. 38, A-C.

1984 *Veryhachium rhomboidium* Downie; Turner, p. 145

Remarks

Observed specimens possess a small rhomboidal vesicle with four simple spines, one eminating from each corner, and up to two processes arising from mid-vesicle. This species resembles *V. minutum* Downie 1959 but is larger, thicker walled and has narrower processes.

Dimensions: Populations from the Venlock type area (in microns): maximum vesicle width 18-26, length of spines 14-20. Number of specimens measured 5.

Material: 5 specimens.

Occurrence: *Veryhachium rhomboidium* was recovered from the Buildwas and Coalbrookdale formations of the Lower Hill Farm Borehole.

Downie (1959) recovered *V. rhomboidium* from the Venlock Shales (Coalbrookdale Formation) of the type area; he recorded its range in Britain as being early Llandovery to late Ludlow (Downie 1984). Smelror (1986) recorded *V. rhomboidium* from the late Llandovery of Norway it has also been found in the upper Devonian of Belgium (Stockmans & Willière 1960) and the Llandovery and Venlock of Belgium (Martin 1969).

Veryhachium trispinosum Formgroup (Eisenack 1938) Deunff 1954 _ex_ Downie 1959

(Pl. 25, figs. 6,10,11; Pl. 30, figs. 4-7)

1938 _Hystrichosphaeridium trispinosum_ Eisenack, p. 16, fig. 2.

nom. nud. 1942 _Hystrichosphaeridium geometricum_ Deflandre, p. 215, fig. 9.

1945 _Hystrichosphaeridium geometricum_ Deflandre; Deflandre, p. 21, pl. 2, figs. 2-5.

1954 _Veryhachium geometricum_ (Deflandre); Deunff n. comb., p. 26-27, pl. 2, figs. 2-5.

1954 _Veryhachium trispinosum_ (Eisenack); Deunff n. comb., p. 306, fig. 13.

1958 _Veryhachium trisulcum reductum_ Deunff, p. 27, pl. 1, figs. 1,3,8, 10-12,14,16,17,22,23.

1959 _Veryhachium trispinosum_ (Eisenack) Deunff; Downie, p.69.

1961 _Veryhachium reductum_ (Deunff); De Jekhowsky n. comb., p. 210-212.

1962 _Veryhachium downiei_ Stockmans & Willière, p. 47-48, pl. 2, figs. 20-22.

1964 _Veryhachium trispinosum_ Formgroup (Eisenack) Deunff; Cramer, pp. 305-307, pl. VIII, fig. 26.

1967 _Veryhachium trispinosum_ (Eisenack) Deunff; Lister & Downie, p. 173.

1973a _Veryhachium trispinosum_ (Eisenack) Deunff; Thusu, p. 803, pl. 106, fig. 9

1974 *Veryhachium roscidum* Wicander, p. 22, pl. 2, fig. 3.

1983 *Veryhachium trispinosum* (Eisenack) Deunff; Dorning, p.37.

1985 *Veryhachium trispinosum* (Eisenack) Deunff; Mabillard & Aldridge, p. 92.

1986 *Veryhachium trispinosum* (Eisenack) Deunff; Smelror, p. 151-152.

1987 *Veryhachium downiei* Stockmans & Willière; Priewalder, p. 55, pl. 7, fig. 4,12; pl. 14, fig. 10.

1987 *Veryhachium geometricum* (Deflandre) Deunff; Priewalder, p.56, pl. 14, figs. 7-9.

1987 *Veryhachium* cf. *reductum* (Deunff) De Jekhowsky; Priewalder, p. 58, pl. 14, fig. 12.

Remarks

The Formgroup as suggested by Cramer (1964, pp. 305-306) and used here covers the following species and their transitional forms: *Veryhachium reductum* (Deunff 1959) De Jekhowsky 1961, *V. downiei* Stockmans & Willière 1962, *V. trisulcum* Deunff 1959, *V. trispinosum* (Eisenack 1938) Deunff 1954 *ex* Downie 1959, *V. geometricum* (Deflandre 1942) Deunff 1954 *ex* Downie 1959 and *V. roscidum* Wicander 1974; these transitional forms show a variation through forms with a convex, triangular, often inflated central body to forms with a concave, triangular, rarely inflated body. All forms possess only three processes. These are variable in length from shorter than the vesicle to twice the vesicle length. Most observed specimens possess a triangular vesicle with convex sides and typically three short processes.

Dimensions: Populations from the Venlock type area (in microns): maximum vesicle width 24-33, length of processes 3-40. Number of specimens measured 10.

Material: 42 specimens.

Occurrence: Veryhachium trispinosum was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area; the Nant-ysgollon Shales of Central Wales and the Denbigh Grits of North Wales.

In the Welsh Borderlands Veryhachium trispinosum has previously been recorded from the Purple Shales and the Buildwas and Coalbrookdale formations (Downie 1959; Mabillard & Aldridge 1985); it has also been recorded from the Wenlock Limestone of Dudley in the West Midlands (Dorning 1983), the Silurian and early Devonian of Spain (Cramer 1964), the Wenlock of Canada (Cramer 1970), the Silurian of Greenland, (Armstrong & Dorning 1983), and the Llandovery and early Wenlock of Norway (Smelror 1986).

Veryhachium wenlockium Formgroup (Downie 1959) Downie & Sarjeant 1964

(Pl. 26, figs. 1,3; Pl. 30, figs. 8-10)

1959 Veryhachium tetraedron var. wenlockium Downie, p. 62, pl.12, figs. 9, 11.

1963 Veryhachium europaeum var. wenlockium Downie; Downie, p. 782.

1964 Veryhachium wenlockium Downie; Downie & Sarjeant, p. 153.

1966 Veryhachium europaeum var. wenlockium Downie; Martin, p. 316.

1967 Veryhachium wenlockium (Downie) Downie & Sarjeant; Lister & Downie, p. 173, pl. 23, fig. 10.

Remarks

Observed specimens conform to the original diagnosis and description by Downie (1959, p.62). The taxon is characterised by its triangular vesicle and four processes, one at each corner, and one arising from the centre of the vesicle. The great range in size of observed specimens, and the variation in process length, suggests that *V. wenlockium* may embrace a group of species that cannot be separated, as their overall morphology is simple, and there appears to be no strict pattern to the variation.

Downie (1963, p. 634) suggests a relationship between species of *Deunffia* Downie 1960, *Domasia* Downie 1960 and *Leiofusa* Eisenack 1938 in the Wenlock Shales (Buildwas and Coalbrookdale formations) of the Wenlock type area; the three genera are mainly constrained to the earliest Wenlock (Buildwas Formation) and morphological transitions of these taxa into *Veryhachium* are proposed.

Veryhachium trispinosum (Eisenack 1938) Deunff 1954 *ex* Downie 1959 possesses fewer and shorter processes.

Dimensions: Populations from the Wenlock type area (in microns): maximum vesicle width 10-31, length of processes 10-50. Number of specimens measured 15.

Material: approximately 6000 specimens.

Occurrence: *Veryhachium wenlockium* was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area; the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole; the Denbigh Grits and Lower Nantglyn Flags of North Wales; the Nant-sygollon Shales of Central Wales and the Brinkmarsh Formation of the Tortworth Inlier.

Downie (1959) recovered *V. wenlockium* from the Wenlock Shales (Buildwas and Coalbrookdale formations) of the Wenlock type area as did Dorning (1981a) and Mabillard & Aldridge (1985); it has also been recorded from the Wenlock of Belgium (Martin 1966), Canada Thusu (1973a) and Norway Smelror (1986).

Subgroup *Pteromorphitae* Downie, Evitt & Sarjeant, 1963

Genus *Duvernaysphaera* Staplin 1961 emend. Cramer 1972

1961 *Duvernaysphaera* Staplin, p. 414.

1964 *Helios* Cramer, pp. 329-330.

Type species: by original designation *Duvernaysphaera tenuicingulata* Staplin 1961

Diagnosis: Refer to Cramer 1972, p.162.

Remarks

Pterospermella Eisenack 1972 lacks the radiating rays in the outer membrane that are seen in *Duvernaysphaera*.

Duvernaysphaera aranaides (Cramer 1964) Cramer 1972

(Pl. 29, figs. 9,14)

1964 *Helios aranaides* Cramer, pp. 329-330, pl XIV, fig. 7.

1966 *Duvernaysphaera gothica* (Cramer); Martin, p. 323, pl.I, fig. 6, 15.

1972 *Duvernaysphaera aranaides* (Cramer); Cramer, p. 163, pl.35, fig. 55.

Remarks

Observed specimens have a subspherical central body with a ring of radiating processes that support an outer circular diaphanous membrane. As

Cramer (1972, p.163) noted in the emended diagnosis 'processes have a tendancy to be curved towards the equator'.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 20-45. Number of specimens measured 5.

Material: 11 specimens.

Occurrence: Duvernaysphaera aranaides was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole. It has previously been recovered from Llandovery to Gedinnian strata; its presence has been recorded in NW Spain (Cramer, 1964, 1968); in Belgium (Martin 1966, 1968); NW Africa (Magloire 1969; Jardiné & Yapaudjian 1968); in the USSR (Kirjanov 1978); and in Norway (Smelror 1986). In the Welsh Borderlands D. aranaides has previously been recovered from strata of late Llandovery to late Ludlow age by Lister & Downie (1967), Hill (1974), Dorning (1983) and Mabillard & Aldridge (1985).

Genus Pterospermella Eisenack 1972

Type species: by original designation Pterospermella aureolata (Cookson & Eisenack) Eisenack 1972

Diagnosis: Refer to Eisenack 1972, pp. 596-601.

Remarks

For generic comments see Playford 1977, pp. 35-36.

Pterospermella onondagaensis (Deunff 1955) Eisenack et al. 1973

(Pl. 29, fig. 12)

1955 Pterospermopsis onondagaensis Deunff, pp. 138-149, pl. 27.

1959 Pterospermopsis cf. onondagaensis Deunff; Downie, p. 64, pl. 12, fig. 8.

1964 Pterospermopsis onondagaensis Deunff; Cramer, p. 328, pl. XVI, figs. 9,10; text fig. 35:2

1973 Pterospermopsis onondagaensis Deunff; Thusu, pl. 106, fig. 16, 20.

1973 Pterospermella onondagaensis (Deunff); Eisenack et al., p. 1001.

Remarks

Observed specimens have a spherical vesicle surrounded by a thinner equatorial membrane which is frayed around the edges. The surface of the vesicle and membrane are smooth.

The size and simplicity of morphology distinguishes this species from any other described species of Pterospermella.

Dimensions: Populations from the Wenlock type area (in microns): overall diameter 15-27, diameter of vesicle 9-15. Number of specimens measured 10.

Material: 17 specimens.

Occurrence: Pterospermella onondagaensis was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area (Sheinwoodian to Homerian). P. onondagaensis has been recovered previously from Wenlock to Lower Devonian strata in Canada (Deunff 1955; Thusu 1973); Belgium (Stockmans & Villière 1963) and NW Spain (Cramer 1964). In the Wenlock type area it has previously been recovered from upper Llandovery to middle Wenlock strata (Downie 1959; Hill 1974)

Pterospermella sp. A

(Pl. 29, figs. 8,13)

Description

A species of *Pterospermella* which has a central spherical vesicle with a reticulated surface wall. The ornament on the vesicle does not extend onto the membrane in any of the studied specimens.

Remarks

The reticulation of the central capsule surface wall distinguishes this from any other described species of *Pterospermella*.

Dimensions: Populations from the Wenlock type area (in microns): overall diameter (vesicle and membrane) 28-39, vesicle diameter 14-18. Number of specimens measured 5.

Material: 5 specimens

Occurrence: *Pterospermella* sp. A was recovered from the Coalbrookdale Formation of the Wenlock type area (Sheinwoodian to Homerian).

Subgroup Uncertain

Genus *Carminella* Cramer 1968

Type species: by original diagnosis *Carminella maplewoodensis* Cramer 1968

Diagnosis: see Cramer 1968, p.67.

Remarks: *Carminella* is a monospecific genus bearing some resemblance mophologically to *Geron* Cramer 1968; both taxa do not readily fit into any of the subgroups erected by Downie, Evitt & Sarjeant (1963).

Carminella maplewoodensis Cramer 1968

(Pl. 29, figs. 15,18)

1968 _Carminella maplewoodensis_ Cramer, p.67, pl.1, fig.7.

1969 _Carminella maplewoodensis_ Cramer; Loeblich, p. 712, fig. 6 A-D.

1972 _Carminella maplewoodensis_ Cramer; Cramer, p. 159, pl.34, fig. 48.

Remarks

A complex acritarch with distinctive features that separate it easily from any other described acritarch taxon. Observed specimens conform to the comprehensive description by Loeblich 1969, p. 712.

Dimensions: Populations from the Wenlock type area (in microns): overall length 61-82, diameter of central body 32-45. Number of specimens measured 8.

Material: 11 specimens.

Occurrence: _Carminella maplewoodensis_ was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and from the Coalbrookdale Formation of the Eastnor Park borehole.

Cramer (1968) first recovered _Carminella maplewoodensis_ from the Wenlock of the USA, and subsequently recorded it from middle and upper Silurian strata in NW Spain (Cramer 1969). Hill (1974b) recovered it from Llandovery strata in the Welsh Borderlands. Dorning (1981a) records its range in the Wenlock and Ludlow type areas as Llandovery to late Ludlow; this is consistent with Mabillard & Aldridge's (1985) record of its occurrence over the Llandovery/ Wenlock boundary in the Wenlock type area.

Genus _Geron_ Cramer 1968

Type species: by original designation _Geron guerillerus_ Cramer 1968

Diagnosis: Refer to Cramer 1968, p.219.

Geron sp.A

(Pl. 29, fig. 7)

Description

Observed specimens comprise a spherical inner body, which is darkened, granular and concentrically enveloped by an outer transparent membrane. The membrane is drawn out at one pole into a cylindrical skirt. A number of filose spines emanate from the central inner body and pass through the opening of the polar skirt. The central body possesses a suture which is irregular in form and parallel to the equator.

Remarks

Geron sp.A differs from *Geron guerillerus* Cramer 1968 in that the latter possesses small processes that link the central body and the outer membrane, whereas the former does not. *Geron gracilis* Cramer 1968 is smaller than *Geron* sp.A and does not possess the granular inner body, *Geron amablis* Cramer 1968 possesses a long stiff conical process instead of the skirt and filose processes of *Geron* sp.A.

Dimensions: Populations from the Eastnor Park borehole (in microns): maximum length of vesicle 57-62, diameter of central body 35-38, width of vesicle 42-51. Number of specimens measured 2.

Material: 2 specimens

Occurrence: *Geron* sp. A was recovered from the Woolhope Limestone of the Eastnor Park borehole (Sheinwoodian).

Subgroup Herkomorphitae Downie, Evitt & Sarjeant, 1963

Genus Cymatiosphaera Wetzel 1933, emend. Deflandre 1954

Type Species: by original designation Cymatiosphaera radiata Wetzel 1933.

Diagnosis: see Deflandre 1954, pp. 257-258.

Remarks

Cymatiosphaera has a spherical-ellipsoidal vesicle. Its surface is divided into polygonal fields by membranes which are perpendicular to the vesicle surface.

Dictyotidium Eisenack 1955a, emend. Staplin 1961, differs in that the polygonal fields are delineated by solid ridges without membranes.

Cymatiosphaera fragilis sp.nov.

(Pl. 27, figs. 1-3)

? 1964 Cymatiosphaera sp. Cramer, pl. XIV, figs 12,13.

Derivation of Name: From the Latin *frangere* meaning to break.

Holotype: Plate 27, fig. 2 ;MPA 26077, F2, G46/2. BGS Lower Hill Farm borehole, Shropshire (SO 5817 9788).

Diagnosis

There is no central vesicle. Membranes are laevigate and unite to form 12-20 pentagonal fields with a spherical to ellipsoidal shape.

Description

The membranes are relatively high and are well defined, uniting to form irregular pentagonal fields.

Remarks

It is a possibility that processing has removed the central area although it is curious if this is the case why a fragile and complete 'shell' has been left undamaged; if this is a real feature then it suggests that excystment could have been by disintegration of the central area. Cymatiosphaera fragilis sp. nov. is not comparable with any other described species of Cymatiosphaera.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 25-40, height of membranes 2-4, diameter of pentagonal fields 3-10. Number of specimens measured 10.

Material: 20 specimens.

Occurrence: Cymatiosphaera fragilis sp. nov. was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and from the Coalbrookdale Formation of the Eastnor Park borehole.

Cramer (1964) illustrates 'damaged' specimens of ? Cymatiosphaera which bear a resemblance to Cymatiosphaera fragilis sp. nov.; unfortunately he does not record where they were found.

Cymatiosphaera gorstia Dorning 1981a

(Pl. 27, figs. 4-6)

1981a Cymatiosphaera gorstia Dorning, p.185, pl.II, fig.7.

'1991' (in press) Cymatiosphaera llandoveryensis Dorning & Hill, p.6, pl.5, figs.8, 11.

Remarks

Observed specimens conform to the original description (Dorning 1981a, p. 185). Cymatiosphaera gorstia and C. llandoveryensis Dorning & Hill '1991' (in press) are considered to be synonymous in that size of vesicle, number of polygonal fields and height of membranes are comparable; C. gorstia being first described has priority. Both Cymatiosphaera ledburica Dorning 1981a and C. octoplana Downie 1959 are smaller, with fewer fields and higher flanges.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 35-50, height of flanges 2-4. Number of specimens measured 6.

Material: 10 specimens.

Occurrence: Cymatiosphaera gorstia was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area (Sheinwoodian to Homerian).

Dorning (1981a) recovered C. gorstia from the Elton and Bringewood Beds of the type Ludlow (Gorstian) and recorded C. llandoveryensis from the upper Llandovery of the Eastnor Park borehole (Dorning & Hill '1991'). The range of C. gorstia is considered to be continuous from the late Llandovery to the early Ludlow.

Cymatiosphaera heloderma Cramer & Diez 1972a

(Pl. 27, figs. 7-8)

1972a Cymatiosphaera heloderma Cramer & Diez, p. 158, pl.32, fig. 22; pl.34, fig. 46.

1989 Cymatiosphaera heloderma Cramer & Diez; Barron, p. 85-86, fig. 3D

Remarks

Observed specimens conform to the original diagnosis. The most distinguishing feature of this species is the dense foveo-reticulate surface wall of the central body. Division of specimens into polygonal fields by raised membranes perpendicular to the central body helps distinguish this species from Pterospermella sp. A. which possesses a similar ornament but possesses only a simple outer membrane..

Dimensions: Populations from the Wenlock type area and the Eastnor Park borehole (in microns): vesicle diameter 35-50, height of crests 9-12. Number of specimens measured 10.

Material: 47 specimens.

Occurrence: Cymatiosphaera heloderma was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole (Sheinwoodian to Homerian).

Previously C. heloderma has been recovered from the upper Llandovery of Ohio (USA) (Cramer & Diez 1972a); Dorning (1981a) recovered it from the Purple Shales and Buildwas Formation of the Welsh Borderlands (late Llandovery to early Wenlock). C. heloderma has also been recorded from the late Llandovery of Norway (Smelror 1987) and the middle Wenlock of the Cheviot Hills, NE England (Barron 1989).

Cymatiosphaera ledburica Dorning 1981a

(Pl. 27, figs. 14-15)

1981a Cymatiosphaera ledburica Dorning, p. 185, pl. II, figs.13,14.

Remarks

Observed specimens conform generally to the original description (Dorning 1981a, p. 185) in that the vesicle is spherical to subspherical and laevigate. It is divided into eight fields by thin membranes. It was noted in the original description that excystment is by a median split, a feature not observed on the studied specimens. Cymatiosphaera octoplana Downie 1959 differs in that it possesses a granulate ornament.

Dimensions: Populations from the Wenlock type area: vesicle diameter 25-32, height of crests 10-14. Number of specimens measured 10.

Material: 13 specimens.

Occurrence: Cymatiosphaera ledburica was recovered from the Coalbrookdale Formation of the Lower Hill Farm borehole (Sheinwoodian to Homerian). Dorning (1981a) recovered it from the Elton and Bringewood Beds of the type Ludlow area (Gorstian).

Cymatiosphaera octoplana Downie 1959

(Pl. 27, figs. 9-10; Pl. 36, fig. 6)

1959 Cymatiosphaera octoplana Downie, p.63, pl.11, fig.2.

1959 Cymatiosphaera wenlockia Downie, p.63, pl.11, fig.4.

1964 Cymatiosphaera wenlockia Downie; Cramer, p.325, pl.17, figs. 12, 13, 15, 17.

1968 Cymatiosphaera wenlockia Downie; Martin, p.136, pl.3, fig.114; pl.7, fig.331.

1973 Cymatiosphaera octoplana Downie; Eisenack et al., p.315.

1973 Cymatiosphaera octoplana Downie; Eisenack et al., p.363.

1976 Cymatiosphaera wenlockia Downie; Achab, p.1314.

1981a Cymatiosphaera octoplana Downie; Dorning, p.186.

1982 Cymatiosphaera octoplana Downie; Dorning, p.268, pl.2, fig.4.

1983 Cymatiosphaera octoplana Downie; Dorning, p.33, pl.5, fig.17.

1987 Cymatiosphaera cf. octoplana Downie; Priewalder, p.26, pl.2, fig.11, 12.

Remarks

The most characteristic feature of this species is the granular vesicle surface which distinguishes it from other described species of *Cymatiosphaera*.

Dorning (1981a) considered *Cymatiosphaera octoplana* to be synonymous with *C. wenlockia* (Downie 1959, pp. 63-64); the holotype of the latter supports this in that it possesses a granular vesicle surface even though this was not referred to in the original diagnosis; by the order in the original text *C. octoplana* has priority.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 26-34, height of crests 4-7. Number of specimens measured 10.

Material: 444 specimens.

Occurrence: *Cymatiosphaera octoplana* was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area; the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole; the Dolyhir Limestone of Old Radnor and from the Brinkmarsh Formation of the Tortworth Inlier.

Downie (1959) recovered *C. octoplana* from the Wenlock Shales (Coalbrookdale Formation) of the type area; Dorning (1981a) recorded its range there as being late Llandovery to early Ludlow; it has also been recorded in similar age sediments from the Wenlock type area by Mabillard & Aldridge (1985). *C. octoplana* has previously been recorded from the Wenlock of Scotland (Dorning 1982) and NE England (Barron 1989), the Llandovery and Wenlock of Norway (Smelror 1986), the late Llandovery and Wenlock of Canada (Achab 1976; Thusu 1973a) and the late Llandovery and early Wenlock of Gotland (Cramer *et al*. 1979).

Cymatiosphaera pavimenta (Deflandre 1945) Deflandre 1954

(Pl. 27, figs. 11-13; Pl. 30, fig. 3)

1945 *Michrystridium pavimentum* Deflandre, p.68, pl.3, fig.21.

1954 Cymatiosphaera pavimenta (Deflandre); Deflandre n. comb., p.258.

1959 Cymatiosphaera pavimenta (Deflandre) Deflandre; Downie, p.63, pl.11, figs. 8,9.

Remarks

A very small species of Cymatiosphaera with a characteristic division of the vesicle by low membranes. The small size distinguishes it from any other described species of Cymatiosphaera.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 10-22, height of crests 1-2. Number of specimens measured 10.

Material: 128 specimens.

Occurrence: Cymatiosphaera pavimenta was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area, the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole, the Brinkmarsh Formation of the Tortworth inlier and the Denbigh Grits of North Wales (?Telychian to Sheinwoodian).

C. pavimenta has previously been recorded from the Wenlock of France (Deflandre 1945,1954) and the late Llandovery to early Wenlock of Norway (Smelror 1986). A comparable form has been recovered from the early Llandovery of Canada (Eley & Legault 1988).

Dorning (1981a) recorded Cymatiosphaera pavimenta from the Coalbrookdale Formation of the Wenlock type area using its appearence to define the base of the C. pavimenta Biozone (Dorning & Bell 1987), this corresponds to the middle Wenlock (late Sheinwoodian to early Homerian); its range is here extended in the Wenlock type area to include the early Sheinwoodian and in the Malverns the range can be possibly extended into the latest Telychian (Llandovery).

Cymatiosphaera pentagonalis Kirjanov 1978

(Pl. 27, figs. 16-18)

1978 *Cymatiosphaera pentagonalis* Kirjanov, p.30, pl. v, figs. 3,5.

Remarks

The observed specimens are typified by the possession of a pentagonal to sub-spherical central body and an outer body which is divided into 6-8 large pentagonal fields, the edges of the fields are extended into high membranes. In contrast *Cymatiosphaera octoplana* Downie 1959 has a granular vesicle with lower crests. *C. gorstia* Dorning 1981a has more fields and lower crests.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 26-36, height of crests 15-24, total diameter 47-54. Number of specimens measured 10.

Material: 218 specimens.

Occurrence: *Cymatiosphaera pentagonalis* was recovered from the Coalbrookdale Formation of the Wenlock type area (Sheinwoodian to Homerian). Kirjanov (1978) first recorded it from the Wenlock of Podolia (USSR). Specimens comparable to *C. pentagonalis* have also been recorded from the Mid-Wenlock of the Cheviot Hills, NE England (Barron 1989).

Genus *Dictyotidium* Eisenack 1955a emend. Staplin 1961

Type species: by original designation *Dictyotidium dictyotum* (Eisenack) Eisenack 1955a.

Diagnosis: Refer to Staplin 1961, p. 417.

Remarks: *Dictyotidium* is characterized by low solid ridges which divide the surface of the vesicle into fields. Some ornamentation may be present.

Dictyotidium cf. *cavernosulum* Playford 1977

(Pl. 27, fig. 20)

cf. 1977 *Dictyotidium cavernosulum* Playford, p.18, pl.5, figs. 5-8.

Remarks

The thick vesicle wall and uniform fine reticulate sculpture of *Dictyotidium cavernosulum* is present on observed specimens although more typical specimens are larger. Lacunae are subcircular to roundly elliptical or roundly polygonal in outline. An excystment mechanism was not observed.

The fineness of the vesicles reticulate sculpture serves to distinguish this species from otherwise similar members of the genus.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 28-42. Number of specimens measured 5.

Material: 5 specimens.

Occurrence: *Dictyotidium* cf. *cavernosulum* was recovered from the Buildwas and Coalbrookdale formations of the Lower Hill Farm borehole (Sheinwoodian).

Playford (1977) first recorded *D. cavernosulum* from the Lower Devonian (Emsian) of Canada.

Dictyotidium dictyotum (Eisenack 1938) Eisenack 1955a

(Pl. 27, fig. 19)

1938 *Leiosphaeridia dictyota* Eisenack, p.27, pl.3, fig. 8 a-c.

1955a *Dictyotidium dictyotum* (Eisenack); Eisenack n.comb., p.179, pl.4, fig. 12-13.

Remarks

A relatively large species of *Dictyotidium* possessing well defined pentagonal fields. *D. stenodictyum* Eisenack 1965b is generally smaller and has more fields.

Dimensions: Populations from the Wenlock type area (in microns): vesicle diameter 55-95, height of ridges 2-3. Number of specimens measured 10.

Material: 45 specimens.

Occurrence: *Dictyotidium dictyotum* was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole.

Eisenack (1955a) recovered *D. dictyotum* from the Wenlock of Gotland; it has been recorded previously from the Llandovery and Wenlock of the Wenlock type area (Mabillard & Aldridge 1985; Dorning 1981a). Smelror (1986) recovered it from the upper Llandovery and lower Wenlock of Norway.

Dictyotidium stenodictyum Eisenack 1965a

(Pl. 27, fig. 21)

1965a *Dictyotidium stenodictyum* Eisenack, pp. 264-265, pl.22, figs. 2,3.

Remarks

The vesicle of Dictyotidium stenodictyum is typically covered with many small polygonal fields, it is larger than D. polygonium Staplin 1961 but smaller than D. dictyotum (Eisenack) Eisenack 1955a.

Dimensions: Populations from the Venlock type area (in microns): vesicle diameter 35-45, height of ridges <1. Number of specimens measured 8.

Material: 12 specimens.

Occurrence: Dictyotidium stenodictyum was recovered from the Buildwas Formation of the Venlock type area.

Eisenack recorded D. stenodictyum from the Llandovery and Wenlock of Gotland; it has previously been recovered from the upper Llandovery and Wenlock of the Wenlock type area (Dorning 1981a; Mabillard & Aldridge 1985).

Subgroup *Netromorphitae* Downie, Evitt & Sarjeant 1963

Genus *Deunffia* Downie 1960

Type species: by original designation *Deunffia monospinosa* Downie 1960.

Diagnosis: Refer to Downie 1960, p. 198.

Remarks

Species of *Deunffia* possess only one process situated at one pole of the vesicle, the process may be simple or branched; species of *Domasia* Downie 1960, in contrast, possess processes at both poles of the vesicle.

Deunffia brevispinosa Downie 1960

(Pl. 28, fig. 1)

1960 *Deunffia brevispinosa* Downie, p. 198, pl.1, figs. 4,6.

1970 *Deunffia brevispinosa* Downie; Cramer, p.56, fig. 14 c,d.

Remarks

Observed specimens possess a microgranulate vesicle that is elongately ellipsoidal in outline and that at one pole possesses a small simple process the other pole being bald. *D. monospinosa* Downie 1960 has an unornamented vesicle and a process that is longer than the length of the vesicle.

Dimensions: Populations from the Wenlock type area (in microns): maximum length of vesicle 15-19, width of vesicle 9-12, length of process 8-11. Number of specimens measured 4.

Material: 4 specimens.

Occurrence: *Deunffia brevispinosa* was recovered from the lower Buildwas Formation of the Lower Hill Farm borehole (Sheinwoodian).

Downie (1960,1963) recovered *D. brevispinosa* from the lower most Buildwas Formation of the Wenlock type area, as did Hill (1974) and Mabillard & Aldridge (1985); Dorning (1981a) recorded its occurrence throughout the Buildwas Formation. It has also been recovered from the early Wenlock of the USA (Cramer 1970), and Russia (Kirjanov 1978).

Hill & Dorning (1984) used the stratigraphical range of *D. brevispinosa* to define their number 5 acritarch biozone; this overlaps with the W1 Biozone of Dorning (1981a). Dorning & Bell (1987) name their biozones (fig. 15.2; p.268) and include a *D. brevispinosa* Biozone

Deunffia furcata Downie 1960 emend.

(Pl. 28, figs. 2,3,11)

1960 *Deunffia furcata* Downie, p. 199, pl.1, figs. 1,9.

1970 *Deunffia furcata* Downie, Cramer, p.57.

1974a *Deunffia brevifurcata* Hill, p.16, pl.1, figs. 5-9.

Emended Diagnosis

Sub-spherical to ellipsoidal hollow, single-layered vesicle. One pole is bald, at the other is a single, hollow process of variable length which distally bifurcates into two equal length branches, these terminate with pointed tips.

Description

Most specimens are laevigate although some display a faint vesicle wall granulation. The process cavity can be continous with the vesicle cavity or is commonly divided into compartments, including the bifurcated portion

Remarks

Hill 1974a proposed a new species Deunffia brevifurcata which he distinguished from Deunffia furcata on the size of the process shaft which in D. brevifurcata is shorter than the vesicle length. Studied specimens of D. furcata in the present study show a morphological gradation from one 'end member' to the other with a process shaft that varies from less than the vesicle size to one that is greater, because of this the specimens here are retained in D. furcata; D. brevifurcata is seen as a junior synonym.

D. monospinosa Downie 1960 possesses one single unbranched process, D. ramusculosa Downie 1960 possesses a process that is distally multifurcate.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): length of vesicle 14-18, width of vesicle 7-11, shaft of process 6-28, branch length 20-25. Number of specimens measured 6.

Material: 21 specimens.

Occurrence: Deunffia furcata was recovered from the Buildwas Formation of the Wenlock type area, the Woolhope Limestone of the Eastnor Park borehole and from the Brinkmarsh Formation of the Tortworth Inlier.

Downie (1960, 1963), Hill (1974a), Dorning (1981a), and Mabillard & Aldridge (1985) recovered D. furcata from the Buildwas Formation of the Wenlock type area; Cramer (1970) recovered it from sediments of early Wenlock age in the USA and Canada.

Deunffia monospinosa Downie 1960

(Pl. 28, fig. 5)

1960 Deunffia monospinosa Downie, p.198, pl.1, fig. 8.

1968 Deunffia monocantha (Deunff); Martin, p. 113, pl.4, fig. 171.

1970 Deunffia monospinosa Downie; Cramer, p.56, pl.I, figs. 11,18,21; pl. III, fig.60, text-fig 14 e,f.

1973 Deunffia monospinosa Downie; Richardson & Ioannides, pl.13, fig.6.

1978 Deunffia monospinosa Downie; Kirjanov, pl.16, figs. 4,6.

Remarks

Deunffia monospinosa is characterised by a small sub-spherical vesicle and the possession of one long unbranched process (2 to 5 times longer than the vesicle). One of the observed specimens possess small hairs emanating from the process at its distal end.

Deunffia brevispinosa Downie 1960 also possesses one unbranched process but it is much shorter than that of D. monospinosa.

Dimensions: Populations from the Wenlock type area (in microns): length of vesicle 16-21, width of vesicle 8-10, length of process 55-75. Number of specimens measured 3.

Material: 3 specimens.

Occurrence: Deunffia monospinosa was recovered from the lower Buildwas Formation of the Lower Hill Farm borehole (Sheinwoodian).

Downie (1960,1963), Hill (1974b), Dorning (1981a) and Mabillard & Aldridge (1985) recovered D. monospinosa from the Purple Shales and lower Buildwas Formation of the type area (Telychian to Sheinwoodian); it has been recovered from the upper Llandovery and lower Wenlock of Belgium (Martin 1966), the USA and Canada (Cramer 1970), the USSR (Kirjanov 1978) and Austria (Priewalder 1987).

Deunffia ramusculosa Downie 1960

(Pl. 28, figs. 4,6)

1960 Deunffia ramusculosa Downie, p.199, pl.I, fig.2.

1970 _Deunffia ramusculosa_ Downie; Cramer, p.58, pl.II, figs. 14,J.K.

1973 _Deunffia ramusculosa_ Downie; Eisenack _et al_., p.397-398.

1978 _Deunffia ramusculosa_ Downie; Kirjanov, p.36-37, pl. XVI, figs. 5,7,10.

1985 _Deunffia ramusculosa_ Downie; Mabillard & Aldridge, text-fig. 4c

Remarks

Observed specimens conform to the original diagnosis by Downie (1960, p.199). _Deunffia ramusculosa_ resembles _D. monospinosa_ Downie 1960 very closely but can be easily distinguished in undamaged specimens by the branching of the distal tip of the process.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns); vesicle length 14-21, vesicle width 8-11, length of single process 34-46, length of branches 4-26. Number of specimens measured 6.

Material: 6 specimens.

Occurrence: _Deunffia ramusculosa_ was recovered from the Buildwas Formation of the Lower Hill Farm borehole and the Woolhope Limestone of the Eastnor Park borehole.

Downie (1960) first described _Deunffia ramusculosa_ from the Buildwas Formation of the Wenlock type area; it was recorded from the Purple Shales and Buildwas Formation in the same area by Mabillard & Aldridge (1985) (late Llandovery to early Wenlock). _D. ramusculosa_ has also been recorded from sediments of a late Llandovery and early Wenlock age in the USA and Canada Cramer (1970).

Genus *Domasia* Downie 1960

Type species: by original designation *Domasia trispinosa* Downie, 1960.

Diagnosis : Refer to Dorning & Hill '1991' (in press), p.10.

Remarks

Dorning & Hill ('1991' (in press), p.10) emended the diagnosis of Downie (1960, p. 199) to include forms with more than three anterior processes and also forms with one anterior process emerging from a mid vesicle position.

Domasia bispinosa Downie, 1960

(Pl. 28, figs. 7,9)

1960 *Domasia bispinosa* Downie, p. 200, pl.1, fig.3.

1967 *Domasia bispinosa* Downie; Martin, p. 320, pl.1, fig.8., text-fig.3.

1970 *Domasia bispinosa* Downie; Cramer, pl.I, figs. 9, 12, 13, 19. text-fig 18a,b.

1973a *Domasia bispinosa* Downie; Thusu, p. 808, fig.11.

Remarks

Domasia bispinosa superficially resembles *D. trispinosa* Downie 1960 in that both possess two anterior processes of a similar length, the difference is that the posterior process is very much reduced in the former.

Dimensions: Populations from the Wenlock type area and Tortworth (in microns): length of vesicle 16-18, width of vesicle 6-9, length of anterior process 14-17, length of posterior process 1-2. Number of specimens measured 5.

Material: 7 specimens.

Occurrence: Domasia bispinosa was recovered from the Buildwas Formation of the Lower Hill Farm borehole.

Downie (1960) first described Domasia bispinosa from the Buildwas Formation of the Wenlock type area; Hill (1974a), Dorning (1981a) and Mabillard & Aldridge (1985) recovered it from the Purple Shales and Buildwas Formation of the Wenlock type area (late Llandovery to early Wenlock); it has also been recovered from sediments of a late Llandovery to early Wenlock age in Belgium (Martin 1966), the USA (Cramer 1970) and Canada (Cramer 1970; Thusu 1973a).

Domasia limaciforme (Stockmans & Willière 1963) Cramer 1970.

(Pl. 28, figs. 8,10)

1963 Veryhachium limaciforme Stockmans & Willière, pp. 453-454, pl.I, figs. 12,14,15,19; text-fig. 6.

1963 Veryhachium delmeri Stockmans & Willière, p. 453, pl.I, fig. 17.

1966 Veryhachium delmeri Stockmans & Willière; Martin, p. 316.

1970 Domasia limaciforme (Stockmans & Willière); Cramer, p.68, pl.I, figs. 16, 27, 28; pl. II, fig. 33.

1973 Domasia limaciforme (Stockmans & Willière) Cramer; Eisenack et al., p.423.

Remarks

Domasia limaciforme is distinguished from other described species of Domasia by the possession of an elongated triangular vesicle. D. trispinosa Downie 1960, in contrast, possesses an ellipsoidal vesicle.

Dimensions: Populations from the Wenlock type area (in microns): vesicle length 18-30, maximum vesicle width 14-18, maximum length of processes 26-31. Number of specimens measured 8.

Occurrence: Domasia limaciforme was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area (Sheinwoodian to Homerian).

Domasia limaciforme was first recorded from the Silurian of Belgium (Stockmans & Willière 1963; Martin 1965, 1966); Cramer (1970) recovered it from the Wenlock of the USA and Canada. In the Welsh Borderlands, D. limaciforme has been recorded from the Purple Shales and Buildwas Formation (late Llandovery to early Wenlock) by Hill (1974a,b), Dorning (1981a) and Mabillard & Aldridge (1985); it has also been recorded from the Wenlock of the USSR (Kirjanov 1978) and Greenland (Armstrong & Dorning 1984) and the Llandovery of Norway (Smelror 1986).

Domasia quadrispinosa Hill 1974b

(Pl. 28, figs. 12-13)

1974b Domasia quadrispinosa Hill, p.18, pl.1, figs. 12-15.

Remarks

An easily recognisable species characteristically possessing three anterior processes and one posterior process; in contrast Domasia trispinosa Downie 1960 possesses two anterior processes whereas D. quinquispinosa Dorning & Hill '1991' (in press) possesses four.

Dimensions: Populations from the Eastnor Park borehole (in microns): vesicle length 31-35, vesicle width 7-9, length of posterior process 18-21, length of anterior process 13-22. Number of specimens measured 2.

Material: 2 specimens.

Occurrence: Domasia quadrispinosa was only recovered from the lower

Woolhope Limestone of the Eastnor Park borehole.

Hill (1974b) first recorded D. quadrispinosa from the top of the Pentamerus Beds to the Buildwas Formation (mid-Llandovery to early Wenlock) of the Welsh Borderlands; Dorning (1981a) recorded its presence there throughout the Buildwas Formation whereas Mabillard & Aldridge (1985) found it only in the upper Llandovery Purple Shales. Smelror (1986) recorded Domasia quadrispinosa from upper Llandovery sediments in Norway.

Domasia trispinosa Downie 1960

(Pl. 28, figs. 14-16)

1960 Domasia trispinosa Downie, p.199, pl.1, fig.7.

1960 Domasia elongata Downie, p.200, pl.1, fig.5.

1987 Domasia trispinosa Downie; Priewalder, p.35, pl.7, fig.3; text-fig 11. (with synonymy to 1984).

Remarks

Hill (1974b, p.17) combined Domasia trispinosa and D. elongata on account of the complete gradation in vesicle length and process length between end members; the species possesses an ellipsoidal central body. D. amphora Martin 1969 is retained for forms with a distinct anterior shaft before distal bifurcation and D. limaciforme (Stockmans & Willière) Cramer 1970 is retained to include those forms with an elongated triangular body.

Dimensions: Populations from the Wenlock type area, the Eastnor Park borehole and the Tortworth Inlier (in microns): length of vesicle 18-22, width of vesicle 8-11, maximum length of anterior processes 17-21, length of posterior process 14-16. Number of specimens measured 10.

Material: 358 specimens.

Occurrence: Domasia trispinosa was recovered from the Buildwas and

Coalbrookdale formations of the Wenlock type area, the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole and the Brinkmarsh Formation of the Tortworth Inlier (Sheinwoodian to Homerian).

Downie (1960) first described _Domasia trispinosa_ from the Buildwas Formation of the Wenlock type area; Hill (1974b), Dorning (1981a) and Mabillard & Aldridge (1985) recorded it from the upper Purple Shales to lower Coalbrookdale Formation of the Wenlock type area (late Llandovery to early Wenlock). _Domasia trispinosa_ has also been recovered from similar age sediments in Belgium (Martin 1966, 1967, 1968), the USA and Canada (Cramer 1970; Thusu 1973a; Achab 1976, Martin 1978), the USSR (Kirjanov 1978), North Africa (Richardson & Ioannides 1973), Scotland (Dorning 1982), Greenland (Armstrong & Dorning 1984), Norway (Smelror 1986) and Austria (Priewalder 1987).

Genus _Eupoikilofusa_ Cramer 1970

Type species: by original designation _Leiofusa striatifera_ Cramer 1964

Diagnosis: Refer to Cramer 1970, p.83.

Remarks: Observed specimens of _Eupoikilofusa_ have a simple crescent shaped vesicle or a vesicle that has alternating curvature down the longitudinal axis; some specimens appear to possess a longitudinal axis that is spiralled. Cramer (1970, p.83) suggested that these variable morphological features which had previously been used to separate specimens at the generic level, were more likely to be specific or possibly even intraspecific variations; studied specimens corroborate this.

Eupoikilofusa cf. _filifera_ (Downie 1959) Dorning 1981a

(Pl. 29, fig. 1)

cf. 1959 _Leiofusa filifera_ Downie, p.65, pl.11, figs. 6,7.

cf. 1964 Leiofusa filifera Downie; Cramer, p. 324, pl XVIII, fig.8; text-fig. 33.

cf. 1978 Leiofusa filifera Downie; Kirjanov, p. 58, pl. XIII, figs. 4,10.

cf. 1981a Eupoikilofusa filifera (Downie); Dorning n. comb., p. 181.

Remarks

Observed specimens possess a fusiform microgranulate or psilate vesicle with long faint muri running down the longitudinal axis. Eupoikilofusa striatifera (Cramer) Cramer 1970 differs in that the muri are much better developed and the vesicle is crescent shaped or spiralled, whereas E. filifera has a straight vesicle. The microgranulate ornament observed on some of the specimens of E. cf. filifera has not been noted before.

Dimensions: Populations from the Wenlock type area (in microns): length of vesicle 100-180, width of vesicle 15-32. Number of specimens measured 5.

Material: 5 specimens.

Occurrence: Eupoikilofusa cf. filifera was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area.

Downie (1959) first recorded E. filifera from the 'Wenlock Shales' (Coalbrookdale Formation) of the Welsh Borderlands, it has also been recovered from Ludlow to lower Gedinnian strata in NW Spain (Cramer 1964) and from the Wenlock and Ludlow of the USSR (Kirjanov 1978); Dorning (1981a, 1983) recovered it from upper Llandovery to lower Ludlow strata in the Welsh Borderlands and the West Midlands of England.

Eupoikilofusa striatifera (Cramer 1964) Cramer 1970

(Pl. 29, figs. 5,6)

1964a *Leiofusa striatifera* Cramer p. 35, pl.2, figs. 9,13

1970 *Eupoikilofusa striatifera* (Cramer); Cramer, p.85-86, pl.III, figs. 51,52,53,54,58,59; pl.IV, figs. 65,72,74. (with synonymy to 1969).

1972a *Eupoikilofusa striatifera* (Cramer) Cramer var. *typica* Cramer & Diez, p.165, pl.34, fig.50; pl.35, fig. 61.

1987 *Eupoikilofusa striatifera* (Cramer) Cramer; Priewalder, p.36, pl.7, figs.5,6,8. (with synonymy to 1985).

Remarks

Eupoikilofusa striatifera covers a group of specimens that have an elongately fusiform vesicle with muri running along their entire length and onto the processes. There is a morphological transition from forms which have hollow process tips to those that have solid process tips, but this is variably developed feature which would be difficult to use as a taxonomic divider at the specific level. Cramer (1972a, p.163) refers to an *E. striatifera* complex to cover variants such as these.

Dimensions: Populations from the Wenlock type area (in microns): vesicle length 109-190, maximum vesicle width 31-45. Number of specimens measured 10.

Material: 174 specimens.

Occurrence: *Eupoikilofusa striatifera* was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area, the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole and from the Nant-ysgollon Shales of Central Wales.

Cramer (1964) first described *Eupoikilofusa striatifera* from lower

Wenlock strata in NW Spain. It has been recorded from the Llandovery and Wenlock of Belgium (Martin 1965, 1966), the Llandovery of Brazil (Brito & Santos 1965, 1967), the Llandovery through to basal lower Gedinnian of North Africa (Jardiné & Yapaudjian 1968; Hill et al. 1985), the Llandovery and Wenlock of the USA and Canada (Cramer 1968, 1970; Thusu 1973a; Jacobson & Achab 1985), the Wenlock of Argentina (Pöthe De Baldis 1975), the Wenlock of France (Rauscher & Robardet 1975), the Llandovery and Wenlock of Norway (Smelror 1986) and the Ludlow of Austria (Priewalder 1987).

E. striatifera has previously been recovered from the Purple Shales and Buildwas Formation of the Wenlock type area (late Llandovery to early Wenlock) (Hill 1974; Mabillard & Aldridge 1985); Dorning (1981a) recorded it throughout the Wenlock and Ludlow in the type areas.

Genus Leiofusa (Eisenack 1934) Eisenack 1938; restr. Cramer 1970

1934 Ovum hispidium Eisenack, p.65.

1938 Leiofusa Eisenack, p.28.

'1991' (in press) Parvifusa Dorning & Hill.

Type species: by original designation Ovum hispidium fusiformis Eisenack 1934.

Diagnosis: Refer to Cramer 1970, p.71.

Remarks

Leiofusa *sensu stricto* as restricted by Cramer (1970, p.71) possesses a simple, hollow vesicle, fusiform in shape, with a simple pointed process at each pole. The vesicle is psilate or microsculptured. The lack of order in the arrangement of sculptural elements distinguishes Leiofusa from Dactylofusa Brito & Santos 1965 and Eupoikilofusa Cramer 1970.

Leiofusa estrecha Cramer 1964

(Pl. 29, fig. 4)

1964 *Leiofusa estrecha* Cramer, p.77, pl.I, fig.8; pl.II, fig.11.

1970 *Leiofusa estrecha* Cramer; Cramer, p.77 (with synonymy to 1968).

Remarks

Observed specimens conform to the emended diagnosis of Cramer (1970, p.77). The excystment mechanism, which was not recorded by Cramer, is by a median split which runs down the longitudinal axis of the vesicle. *L. parvitatis* Loeblich 1969 is much smaller.

Dimensions: Populations from the Wenlock type area (in microns): vesicle length 120-225, vesicle width 22-28. Number of specimens measured 5.

Material: 9 specimens.

Occurrence: *Leiofusa estrecha* was recovered from the Coalbrookdale Formation of the Lower Hill Farm borehole (late Sheinwoodian to Homerian). It has previously been recovered from upper Llandovery to basal Devonian strata in NW Spain (Cramer 1964 to 1968), Brazil (Brito 1967; Brito & Santos 1965), the Sahara (Jardiné & Yapaudjian 1968) and from North Florida (Cramer 1970). Downie (1984) recorded its previously known range in the British Isles as mid Ludlow to early Gedinnian.

Leiofusa parvitatis Loeblich 1969

(Pl. 29, figs. 10-11)

1969 *Leiofusa parvitatis* Loeblich, p.724, fig.18 F,G.

Remarks

A small species of *Leiofusa* possessing one process which is distinctly longer than the other; the long process is often bent over towards its distal tip. As Loeblich (1969, p. 725) remarked excystment is by a small circular pylome at the centre of the vesicle. The central body is fusiform. Leiofusa parvitatis is smaller than other described species of Leiofusa. Dorning & Hill ('1991' in press) erect a new genus Parvifusa with the type species Parvifusa parvitatis, the morphological features that distinguish the genus from Leiofusa are smaller overall dimensions and a more clearly defined vesicle. Specimens are here retained in Leiofusa because the morphological differences are not seen to be great enough to warrant the erection of a new genus; the emended diagnosis of Leiofusa (Cramer 1970, p. 71-72) adequately incorporates L. parvitatis.

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle length 22-36, vesicle width 12-15, process length 22-37. Number of specimens measured 10.

Material: 136 specimens.

Occurrence: Leiofusa parvitatis was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole. L. parvitatis was first recovered from the Wenlock of the USA (Loeblich 1969), it has also previously been recovered from the Purple Shales and Buildwas Formation of the Wenlock type area (Mabillard & Aldridge 1985) and the Wenlock Limestone of Dudley in the West Midlands (Dorning 1983).

Leiofusa tumida Downie 1959

(Pl. 29, figs. 2,3)

1959 Leiofusa tumida Downie, p.65, pl.11, fig.5.

1965 Leiofusa tumida Downie; Martin, pp. 31,32, pl.I, fig.20.

1970 Leiofusa tumida Downie; Cramer, p.78, pl.II, figs. 37,38: text-fig 22J.

Remarks

The hollow subspherical central body and long slender simple polar processes distinguish Leiofusa tumida from other described species of Leiofusa which are mostly fusiform in overall shape. In observed specimens excystment was by a median split which runs equatorially around the central body perpendicular to the length of the processes.

Dimensions: Populations from the Wenlock type area and the Eastnor Park borehole (in microns): length of vesicle 30-42, width of vesicle 15-21, length of process 35-57. Number of specimens measured 4.

Material: 4 specimens.

Occurrence: Leiofusa tumida was recovered from the Coalbrookdale Formation of the Lower Hill Farm borehole and the Woolhope Limestone of the Eastnor Park borehole (Sheinwoodian to Homerian).

Downie (1959) first recorded Leiofusa tumida from the 'Wenlock Shales' (Coalbrookdale Formation) of the Welsh Borderlands; Dorning (1981a) recorded it from the Coalbrookdale Formation, the Wenlock Limestone and the Lower Elton Beds of the Wenlock and Ludlow type areas (mid Wenlock to early Ludlow). It has also been recovered from the upper Llandovery and lower Wenlock of Belgium (Martin 1965), the upper Llandovery to lower Ludlow of the USA and Canada (Cramer 1970) and from the upper Llandovery of Norway (Smelror 1986).

Class *Chlorophyceae*

Genus *Tasmanites* Newton 1875, emend. Eisenack 1958

Type species: by original designation *Tasmanites punctatus* Newton 1875

Diagnosis: Refer to Eisenack 1958, p.6

Remarks: Species of *Tasmanites* are characterised by the relatively large size of the vesicle and the thick wall possessing pores and canals.

Tasmanites cf. *medius* Eisenack 1931

(Pl. 26, fig. 8)

cf. 1931 *Tasmanites medius* Eisenack, p.6, pl.2, figs. 3,4.

cf. 1959 *Tasmanites* cf. *medius* (Eisenack); Downie, p.67, pl.12
, figs. 5,6.

cf. 1978 *Tasmanites medius* (Eisenack); Kirjanov, p.84, pl.II,
figs 5a, 6.

Remarks

Observed specimens differ from the typical forms of *Tasmanites medius* by having a smaller diameter and thinner walls.

Dimensions: Populations from the Wenlock type area (in microns): Diameter of vesicle 45-80, thickness of wall 8-10. Number of specimens measured 8.

Material: 51 specimens.

Occurrence: *Tasmanites* cf. *medius* was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area, the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole and the Brinkmarsh Formation of the Tortworth inlier (Sheinwoodian to Homerian).

Eisenack (1931,1955) recovered *Tasmanites medius* from Ordovician to upper Silurian strata in the Baltic region, Kirjanov (1978) recovered it from upper Ludlow and Přídolí strata in the USSR. Downie (1959,1963) recovered *T.* cf. *medius* from the 'Wenlock Shales' (Coalbrookdale Formation) of the Welsh Borderlands.

7.5. Anteturma Sporites Potonié 1893

Terminology used for the description of spores is that proposed by Potonie & Kremp (1954) with modifications proposed by the international commission for Palaeozoic microfloras (CIMP) (Couper & Grebe 1961).

The Genus and species described is considered as a form taxon based purely on arbitrary morphological criteria.

Turma Triletes Reinsch 1891

Subturma Zonotriletes Valtz 1935

Infraturma Crassiti Bharadwaj & Venkatachala 1961

Genus *Ambitisporites* Hoffmeister 1959

Type species: by original designation *Ambitisporites avitus* Hoffmeister 1959.

Diagnosis: Refer to Hoffmeister 1959, p.331.

Remarks: a simple spore characterized by its smooth wall and equatorial crassitude.

Ambitisporites dilutus (Hoffmeister 1959) Richardson & Lister 1969

(Pl. 26, figs. 4,5,9,10)

1959 *Punctatisporites? dilutus* Hoffmeister pl.1, figs. 9-13.

1969 *Ambitisporites* cf. *dilutus* (Hoffmeister); Richardson & Lister, pp. 229, pl.40, fig.3.

1986 Ambitisporites dilutus (Hoffmeister); Richardson & McGregor, pp. 6-7, pl.1, fig.1.

Remarks

A small subtriangular to subcircular laevigate spore with a distinctive trilete mark and equatorial crassitude. The equatorial crassitude is also present in Ambitisporites avitus Hoffmeister 1959, and although in the latter the thickening is much more pronounced it is possible that these two species intergrade.

There are broad similarities between spores of the avitus-dilutus complex and the species Archaeozonotriletes chulus (Cramer) Richardson & Lister 1969. However,the latter typically has a thicker distal-equatorial wall and a thin proximal wall which is frequently folded into tapering folds or is collapsed (Richardson & Lister 1969).

Dimensions: Populations from the Wenlock type area and Eastnor Park borehole (in microns): vesicle diameter 28-40. Number of specimens measured 10.

Material: 498 specimens.

Occurrence: Ambitisporites dilutus was recovered from the Buildwas and Coalbrookdale formations of the Wenlock type area and the Woolhope Limestone and Coalbrookdale Formation of the Eastnor Park borehole.

Ambitisporites dilutus has previously been recorded from middle Llandovery strata in Libya (Hoffmeister 1959, Gray & Boucot, 1971), the middle and upper Llandovery of the U.S.A. (Pratt et al., 1978; Strother & Traverse 1979; Miller & Eames 1982) and the middle Llandovery to upper Ludlow of the Welsh Borderlands (Aldridge et al., 1980b; Richardson & Lister 1969). Richardson & McGregor (1986) recorded its stratigraphical range as mid Llandovery to mid Přídolí.

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PLATES

PLATE 1

Figure

1,2. Ancyrochitina ancyrea (Eisenack 1931)

1. MPA 26072, C4, V52/4, (x300)
2. MPA 26084, C5, U47/4, (x300)

3,4. Ancyrochitina primitiva Eisenack 1964a

3. MPA 26084, C5, V49/2, (x300)
4. MPA 26083, C3, T43/1, (x300)

5. Ancyrochitina pachyderma Laufeld 1974

5. MPA 26079, C3, T38, (x400)

6. Ancyrochitina cf. diabolus Eisenack 1937, nom. correct. Laufeld 1974

6. MPA 26047, C3, H52/3, (x325)

7,8. Ancyrochitina gutnica Laufeld 1974

7. MPA 26077, C5, T35/3, (x350)
8. Showing details of spines on neck, MPA 26047, C5, V41/2, (x800)

PLATE I

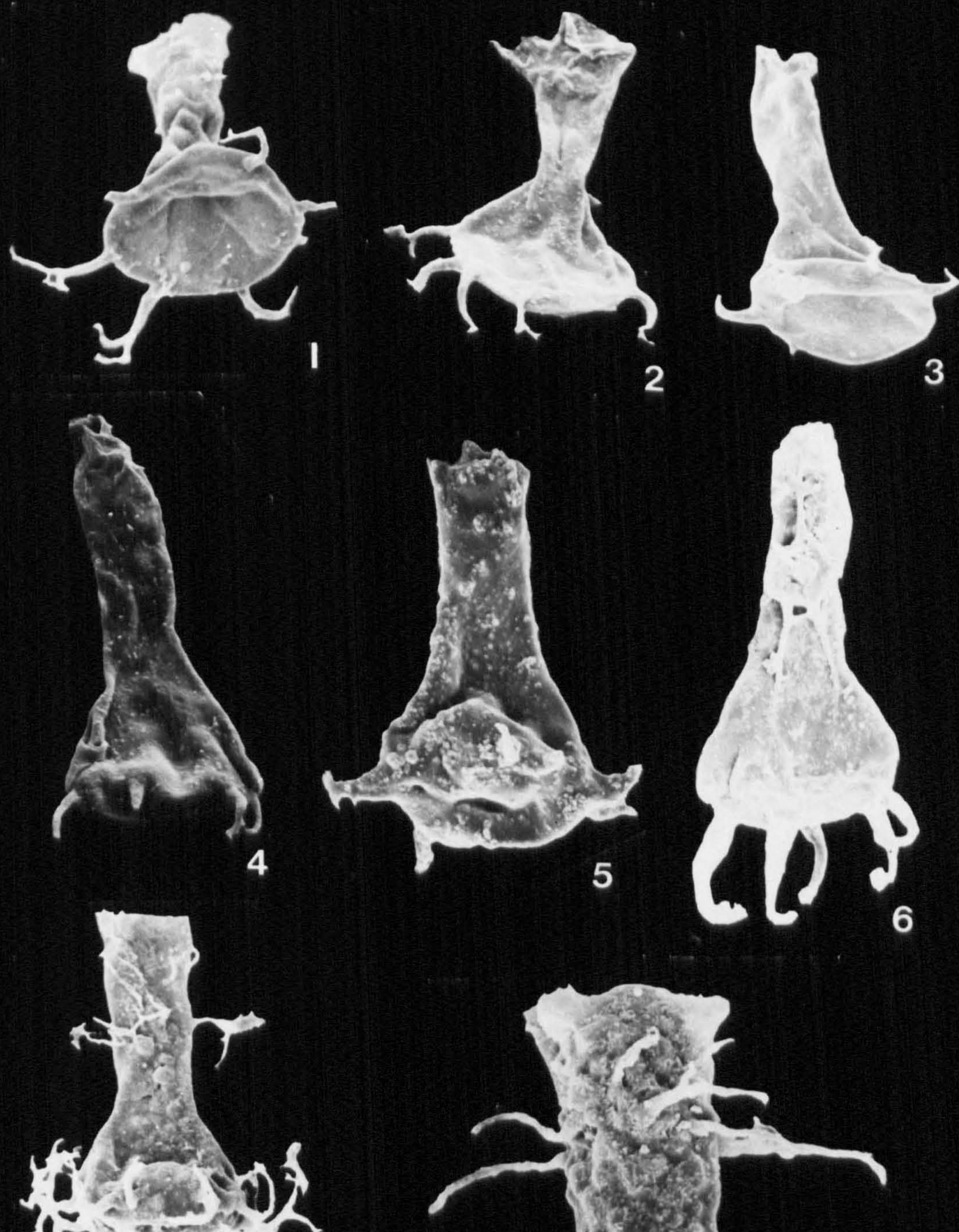


PLATE 2

Figure

1,2. Angochitina longicollis Eisenack 1959 nom. correct.
Laufeld 1974

1. MPA 26084, C5, V48/4, (x300)
2. Showing details of spines on the vesicle, MPA 26084, C5, V48/4, (x1000)

3. Conochitina argillophila Laufeld 1974

3. MPA 26083, C3, J33/1, (x300)

4,6. Conochitina armillata Taugourdeau & De Jekhowsky 1960

4. MPA 26047, C5, W41/4, (x400)
6. MPA 26047, C5, M42/3, (x400)

5,7. Cingulochitina cingulata (Eisenack 1937)

5. WC/PS 3, C3, V46/4, (x350)
7. WC/PS 3, C3, V39/3, (x1000)

PLATE 2

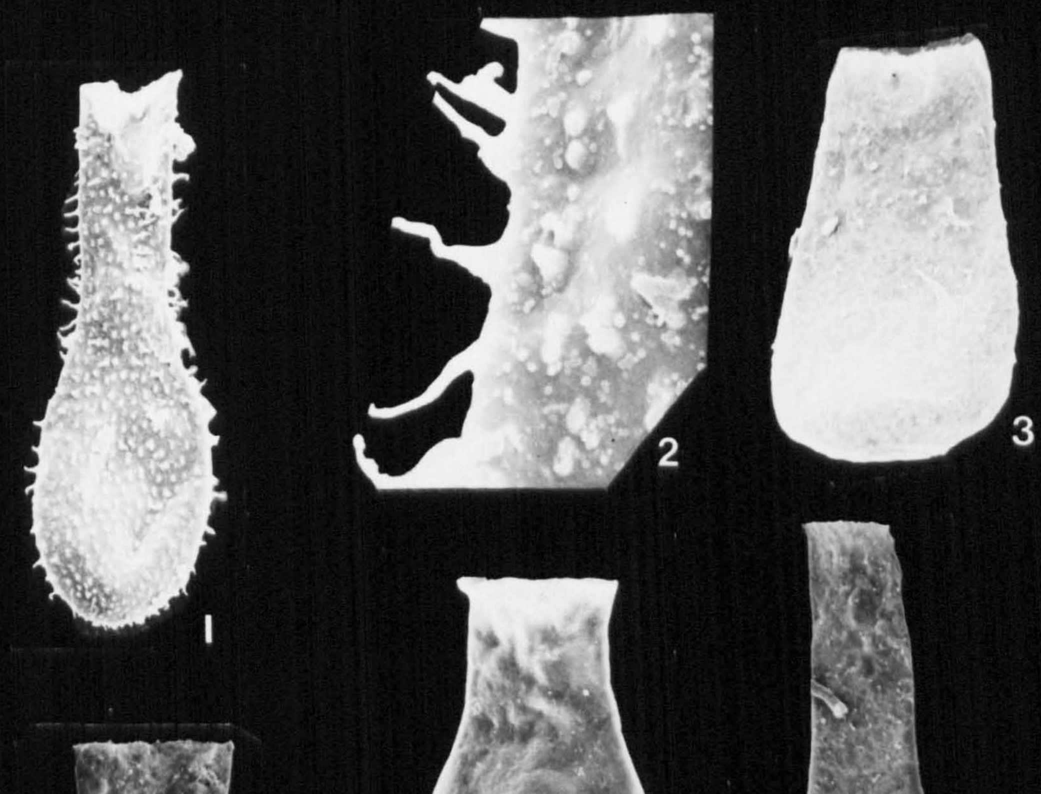


PLATE 3

Figure

1,2. Conochitina pachycephala Eisenack 1964
1. MPA 26076, C3, Z46/3, (x129)
2. MPA 26076, C3, T36/1, (x170)

3,6. Conochitina tuba Eisenack 1932
3. MPA 26047, C4, O37/1, (x450)
6. MPA 26056, C3, N39/1, (x400)

4. Conochitina proboscifera Eisenack 1937
4. MPA 26083, C3, U30/2, (x200)

5. Conochitina proboscifera forma gracilis Laufeld 1974
5. MPA 26072, C4, V49/3, (x200)

7,8. Conochitina visbyensis Laufeld 1974
7. MPA 26076, C3, Y43/4, (x300)
8. MPA 26076, C3, O36/3, (x700)

10. Calpichitina (Densichitina) densa (Eisenack 1962)
10. MPA 26077, C3, U49/3, (x300)

9,11. Eisenackitina cf. lagenomorpha (Eisenack 1931)
9. MPA 26049, C4, U38/3, (x390)
11. MPA 26049, C3, U33/4, (x450)

12. Eisenackitina sp.A
12. MPA 26083, C3, P45/1, (x400)

PLATE 3

PLATE 4

Figure

1-3,6. Eisenackitina varireticulata Swire 1990

1. holotype, MPA 26083, C4, P49/1, (x400)
2. Oral view, MPA 26083, C3, R41/2, (x350)
3. MPA 26083, C6, R34/3, (x350)
6. showing reticulate ornament, MPA 26083, C6, R34/3, (x1100)

4,5,7. Salopchitina bella Swire 1990

4. MPA 26083, C3, T47/1, (x600)
5. MPA 26083, C6, B34/3, (x300)
7. illustrating attachment of appendix to basal margin, MPA 28410, C3, J44/3, (x1100)

8-10. Eisenackitina spongiosa Swire 1990

8. shows dense reticulate ornament extending up to the aperture, MPA 26057, C5, H43/3, (x1100)
9. MPA 26057, C4, K40/4, (x350)
10. holotype, MPA 26057, C3, G33/2, (x400)

PLATE 4

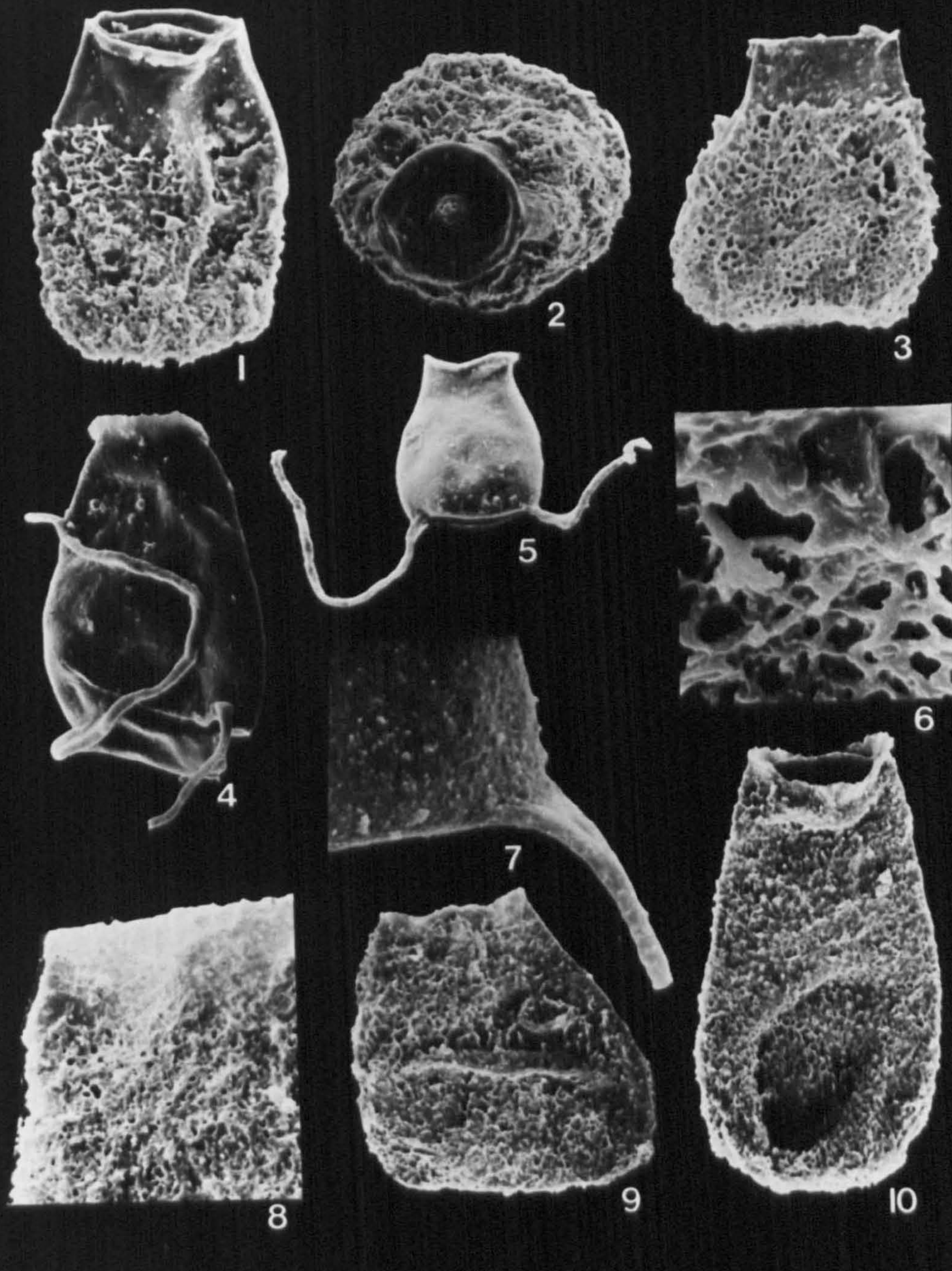


PLATE 5

Figure

1. *Eisenackitina* sp.A

    1. MPA 26082, C3, U34/1, (x400)

2,3. *Eisenackitina* sp.B

    2. MPA 26083, C3, R36/3, (x350)

    3. Showing the details on the neck, MPA 26083, C3, R36/3, (x1000)

4,7. *Linochitina* cf. *erratica* (Eisenack 1931)

    4. MPA 26074, C3, R27/1, (x200)

    7. MPA 26074, C3, K39/1, (x500)

5. *Gotlandochitina spinosa* (Eisenack 1932)

    5. MPA 26056, C3, L30/1, (x350)

6,8. *Margachitina* cf. *catenaria* subsp. *crassipes* Paris 1981

    6. MPA 26055, C3, M38/3, (x350)

    8. MPA 26055, C3, R38/4, (x400)

PLATE 5

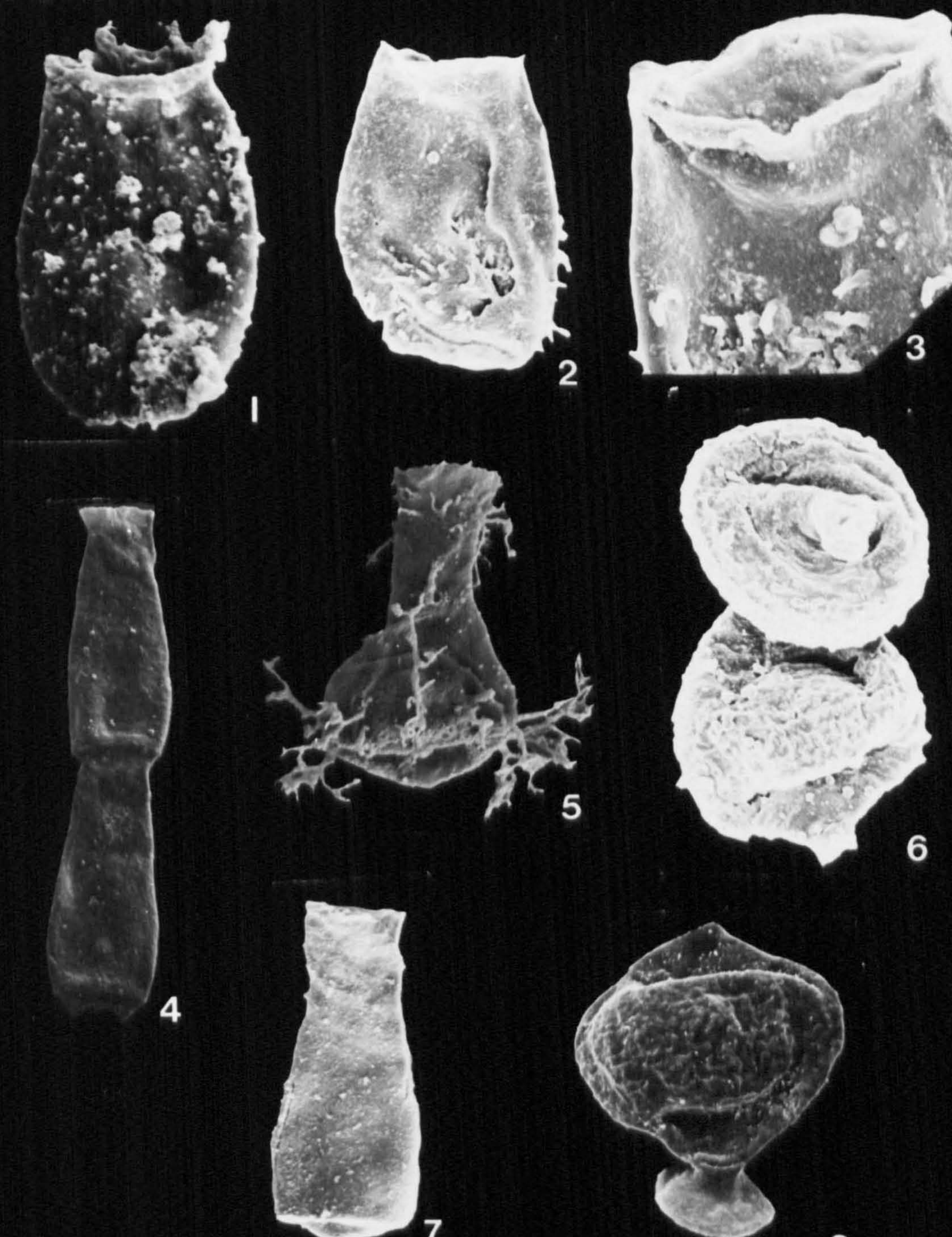


PLATE 6

Figure

1,2,4. Margachitina margaritana (Eisenack 1937)

1. MPA 26072, C3, N29, (x400)
2. MPA 26072, C3, Q33, (x200)
4. MPA 26072, C4, D43/1 (x400)

3,6. Sphaerochitina sp.

3. MPA 26046, C4, D34/1, (x450)
6. MPA 26046, C4, D34/1, (x1100)

5. Graptolite sicula

5. MPA 26047, C3, U38/2, (x350)

7. Salopochitina bella Swire 1990

7. MPA 26083, C3, K39/3, (x500)

8. Plant cuticle

8. MPA 26056, C3, V22/1, (x500)

PLATE 6

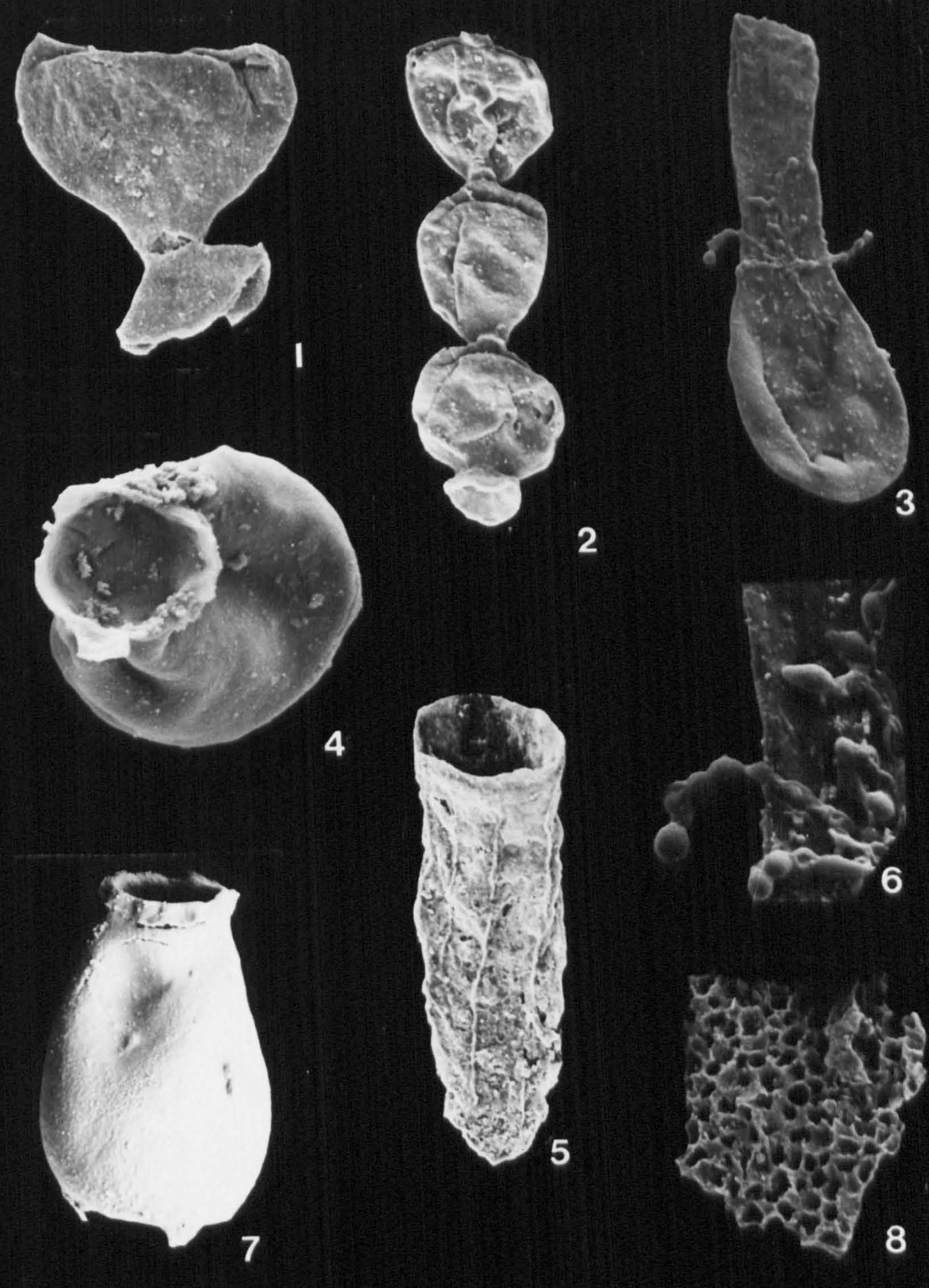


PLATE 7

all magnifications x350 unless otherwise stated

Figure

1,4. Ancyrochitina gutnica Laufeld 1974

1. MPA 26075, C1, V32/2
4. MPA 26077, C1, T32/4

2. Ancyrochitina pachyderma Laufeld 1974

2. MPA 26079, C1, T43/3

3. Angochitina longicollis Eisenack 1959 nom. correct. Laufeld 1974

3. MPA 26084, C1, F53/2

5,8. Cingulochitina cingulata (Eisenack 1937)

5. OER/3, C1, 044/1, (x250)
8. WC/PS1, C1, T32/2, (x100)

6. Ancyrochitina cf. diabolus Eisenack 1937

6. MPA 26048, C1, H47/2

7. Ancyrochitina cf. ancyrea (Eisenack 1931)

7. OER/6, C1, S22/3

PLATE 7

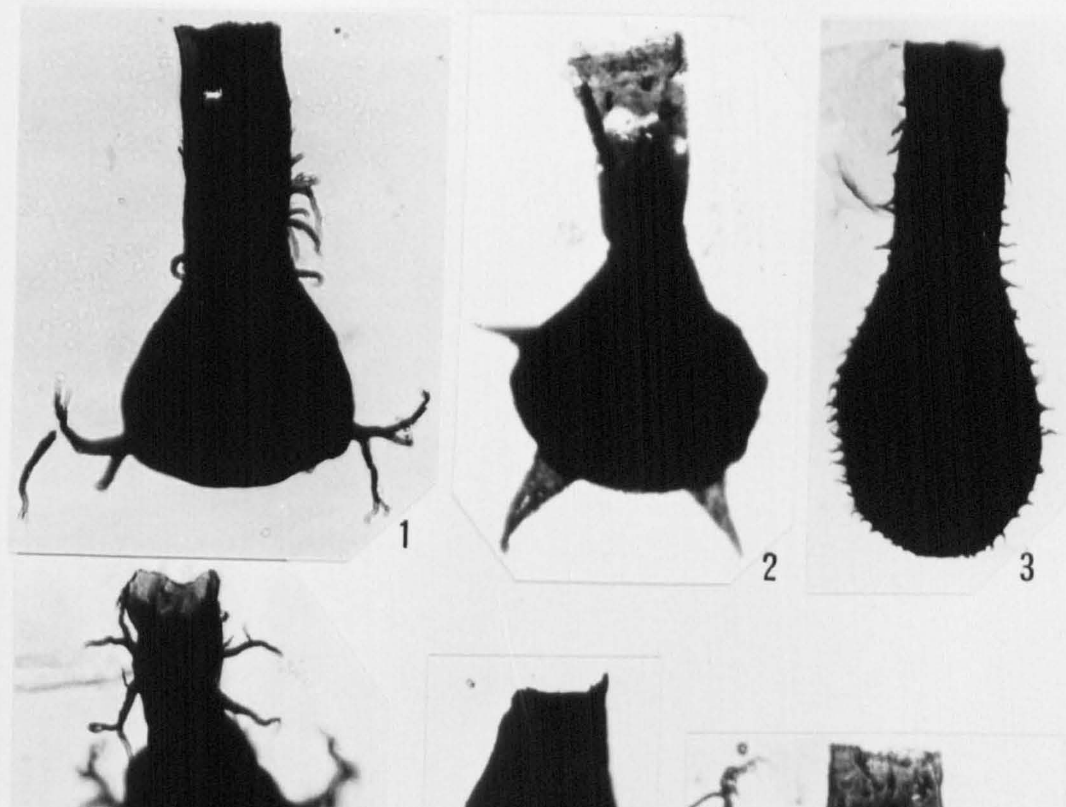


PLATE 8

all magnifications x350 unless otherwise stated

Figure

1. *Conochitina argillophila* Laufeld 1974
   1. MPA 26082, C1, P32/4

2. *Conochitina tuba* Eisenack 1932
   2. OER/1, C1, P40/3

3,5. *Conochitina granosa* Laufeld 1974
   3. MPA 26045, C1, S53, (x450)
   5. MPA 26045, C2, S52/1

4. *Conochitina proboscifera* Eisenack 1937
   4. BRAIN/PS1, Q39/1

6. *Conochitina visbyensis* Laufeld 1974
   6. OER/F1, T44/1

7,8. *Calpichitina (Densichitina) densa* Eisenack 1962
   7. MPA 28483, T43/3
   8. MPA 26080, C1, L33

PLATE 8

PLATE 9

Figure

1,3. Gotlandochitina martissoni Laufeld 1974

1. MPA 26074, C2, F40/1, (x350)
3. MPA 26072, C1, O49/1, (x350)

2,5,6,8. Sphaerochitina aff. sphaerocephala (Eisenack 1932)

2. LRG 3/2, 3, Y47, (x200)
5. LRG 3/2, 4, S41/2, (x200)
6. LRG 3/2, 1, J38/1, (x200)
8. LRG 3/3, 2, N38/1, (x200)

4. Eisenackitina cf. lagenomorpha (Eisenack 1931)

4. MPA 28477, C1, V36/2, (x250)

7,9. Margachitina margaritana (Eisenack 1937)

7. VC/PS 2, C2, W50/3, (x350)
9. MPA 26084, C1, T31/2, (x350)

PLATE 9

PLATE 10

all magnifications x250 unless otherwise stated

Figure

1-3. *Salopochitina bella* Swire 1990

1. illustrates two long appendices and a third incipient one, MPA 26083, C2, T39/3
2. the specimen possesses one long appendix which is attached to the centre of the base of the vesicle, MPA 26083, C1, V31/3
3. holotype, MPA 26083, C2, P50/2

4-7. *Eisenackitina varireticulata* Swire 1990

4. MPA 26083, C1, V45/1
5. MPA 26083, C2, H32/4
6. MPA 26083, C1, U38/1
7. illustrates reticulate ornament, MPA 26083, C2, P39/3, (x650)

8. *Eisenackitina spongiosa* Swire 1990

8. MPA 26057, C1, P47/2

PLATE 10

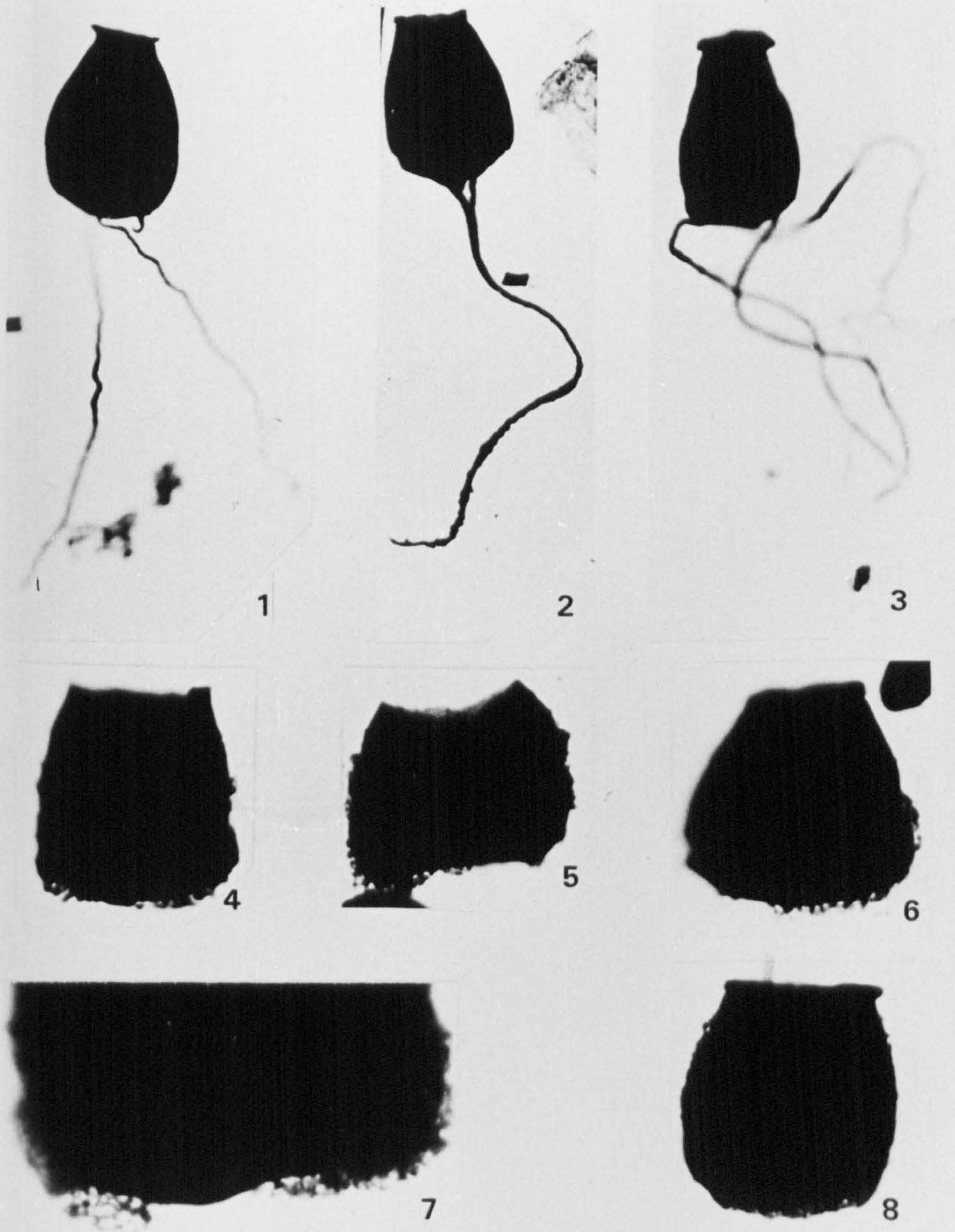


PLATE 11

Magnifications x500 unless otherwise stated

Figure

1-4. Alveosphaera ? deflandrei (Stockmans & Willière 1963) Priewalder 1987
1. MPA 26076, F1, H39
2. MPA 26076, F1, Q39/1
3. MPA 26073, F2, O49/2
4. MPA 28484, F2, S35/2

5-7. Alveosphaera ? densisporata Priewalder 1987
5. MPA 26062, F1, E52
6. WCA/PS 3, F1, K46/4
7. MPA 26062, F2, M48/1

8. Alveosphaera sp. A
8. MPA 28415, F2, L46

9-11. Helosphaeridium citrinipeltatum (Cramer & Diez 1972a) Dorning 1981a
9. MPA 26052, F1, U35
10. MPA 28415, F1, R36/3
11. MPA 26080, F1, L32

12. Helosphaeridium echinoformis Priewalder 1987
12. MPA 26076, F1, R31/3

13-14. Helosphaeridium malvernensis Dorning 1981a
13. WC/PS 10, F1, K46/4
14. WC/PS 12, F2, K50

PLATE 11

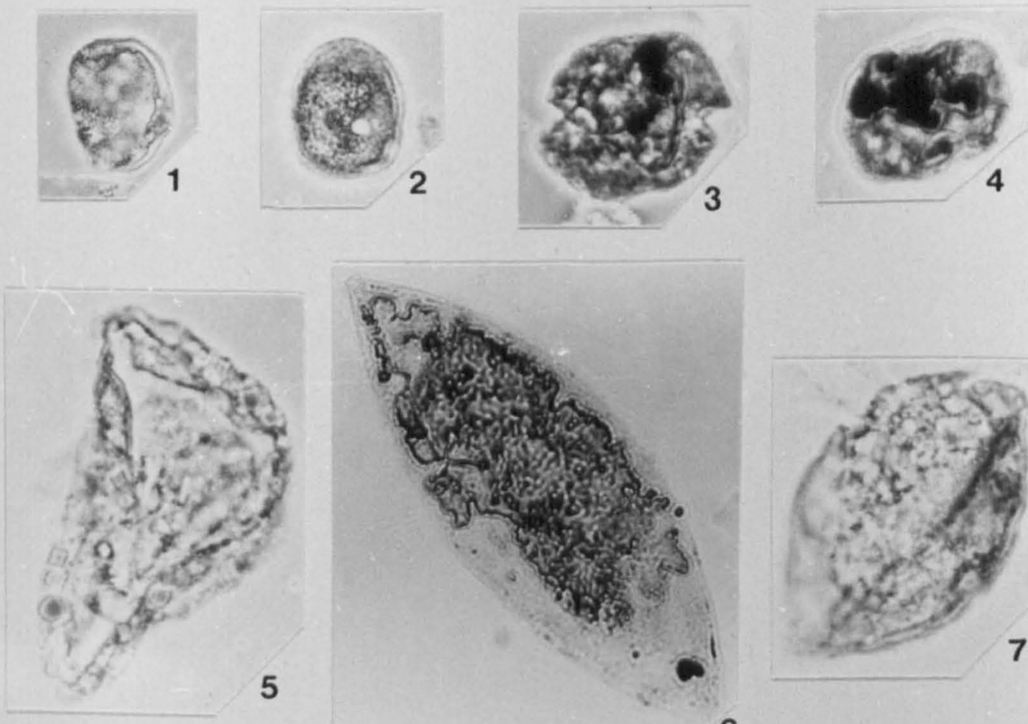


PLATE 12

Magnifications x1000 unless otherwise stated

Figure

1. *Helosphaeridium malvernensis* Dorning 1981a
   1. WC/PS 10, F1, O48/2

2-4. *Helosphaeridium pseudodictyum* Lister 1970
   2. WC/PS 11, F1, O48/4
   3. WC/PS 11, F1, O52/4
   4. WC/PS 12, F1, J45/4

5-6. *Leiosphaeridia laevigata* Stockmans & Willière 1963
   5. BR/PS 1, 3, V47/3
   6. BR/PS 1, 3, R47

7. *Leiosphaeridia* sp.
   7. MPA 26071, C3, M44, (x200)

PLATE 12

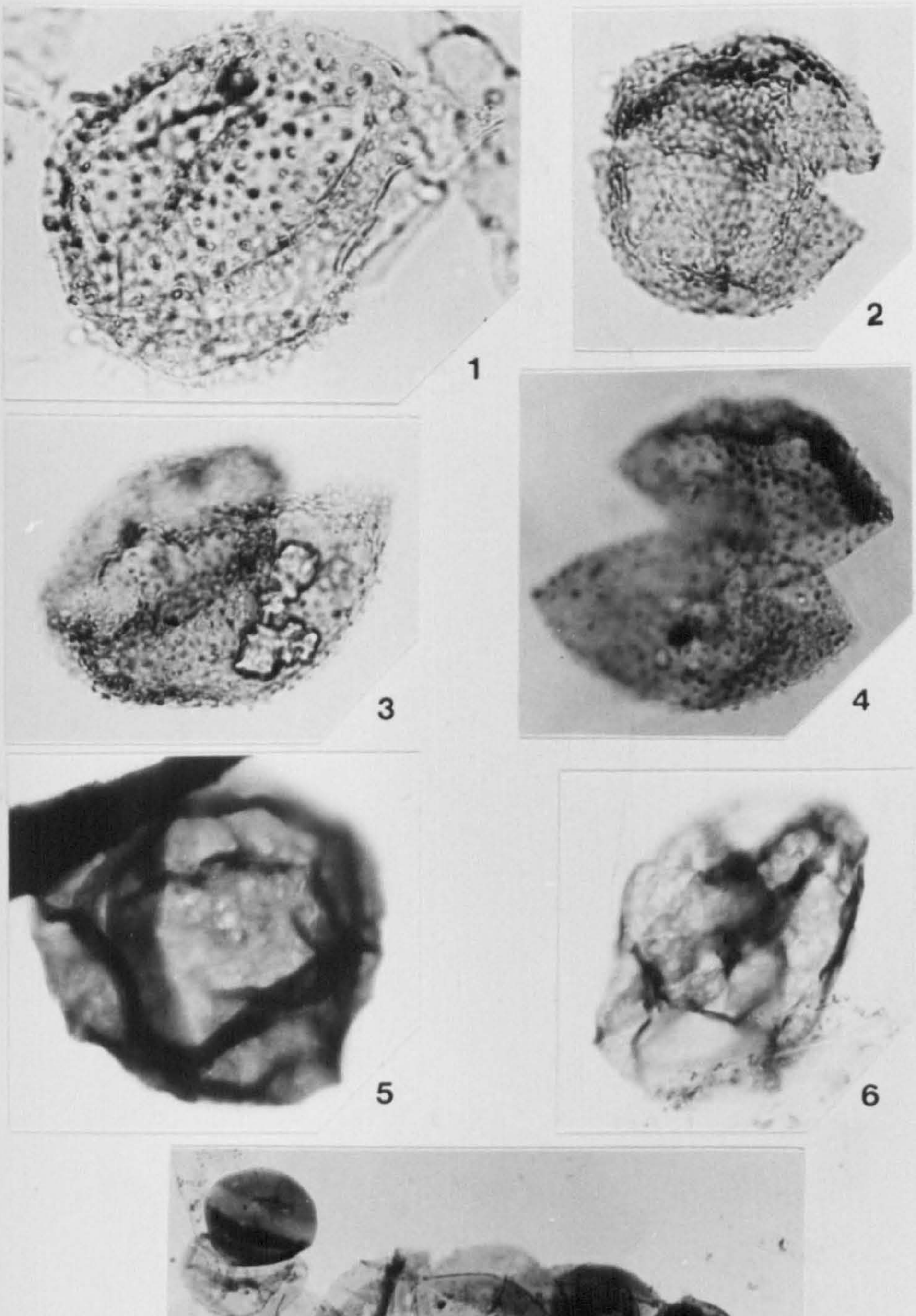


PLATE 13

Magnifications x500 unless otherwise stated

Figure

1. *Leiosphaeridia laevigata* Stockmans & Willière 1963
   1. BR/PS 4, 1, T37, (x750)

2-3. *Leiosphaeridia wenlockia* Downie 1959
   2. MPA 26080, F1, Q35/1
   3. MPA 28411, F1, T41

4-5. *Lophosphaeridium citrinum* Downie 1963
   4. MPA 26084, F1, T43/3
   5. MPA 26080, F1, L35/2

6-9. *Lophosphaeridium microspinosum* (Eisenack 1954) Downie 1963
   6. MPA 26054, F1, O46/1
   7. MPA 26054, F1, M48/3
   8. MPA 26064, F2, L48/1
   9. MPA 28410, F2, J39/3

10-11. *Lophosphaeridium* cf. *papillatum* (Staplin 1961) Downie 1963
   10. MPA 26067, F1, T43/3
   11. MPA 26073, F1, X37/4

PLATE 13

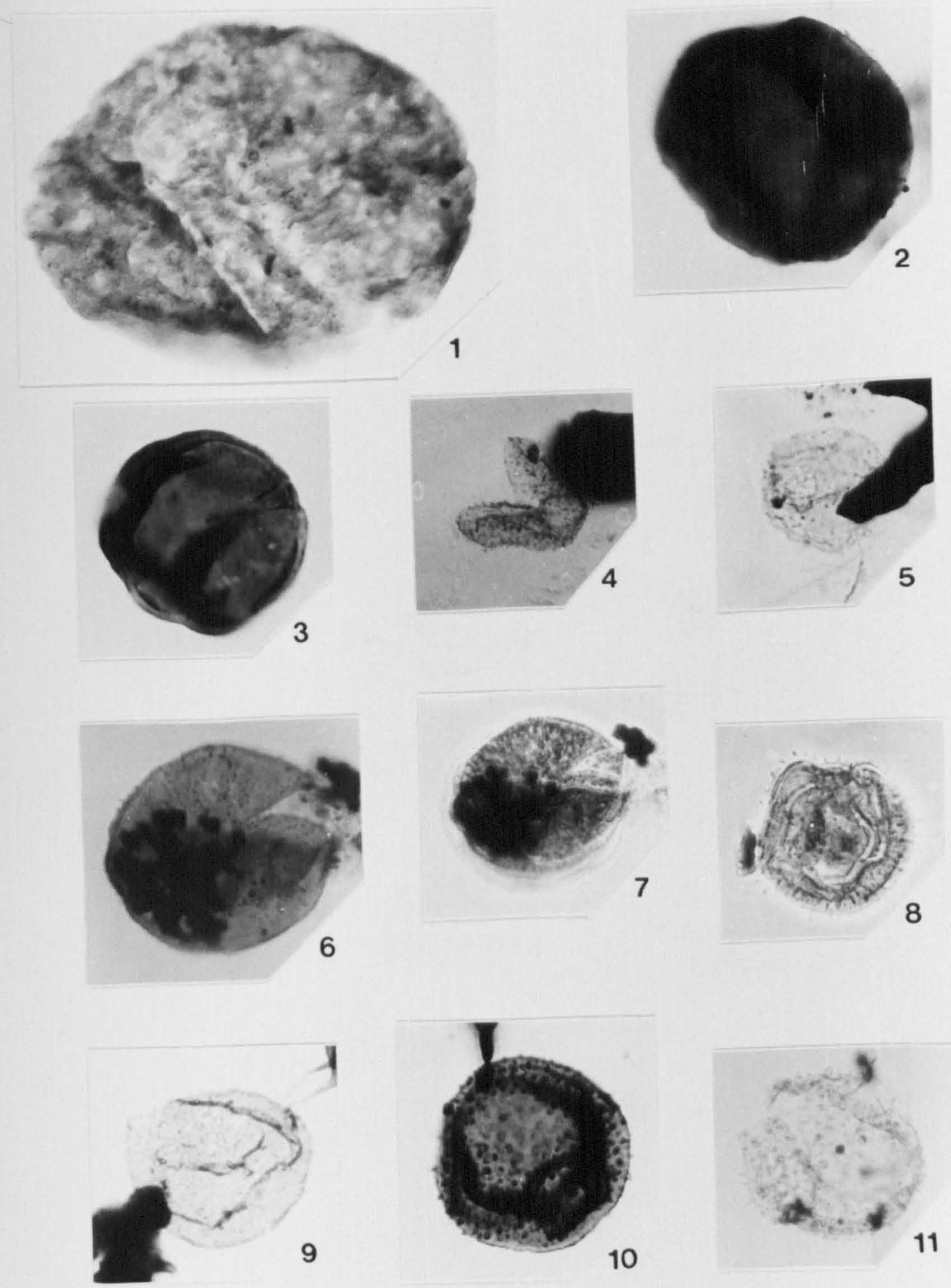


PLATE 14

Magnifications x500 unless otherwise stated

Figure

1-4. Lophosphaeridium pulchrum sp.nov.

1. holotype, MPA 26067, F2, G40/3
2. MPA 26063, F2, U54
3. MPA 26063, F2, J51/2
4. MPA 26058, F1, P49

5,7,8. Moyeria uticaensis Thusu 1973b

5. MPA 26058, F1, P38
7. MPA 26058, F1, H29/4
8. MPA 26047, F1, H37

9. Nanocyclopia sp. A

9. MPA 28412, F2, S47/4

6,10-11. Psenotopus chrondrocheus Tappan & Loeblich 1971

6. MPA 26077, F2, D33/3
10. MPA 26080, F1, U32/1
11. MPA 26080, F1, M42/3

PLATE 14

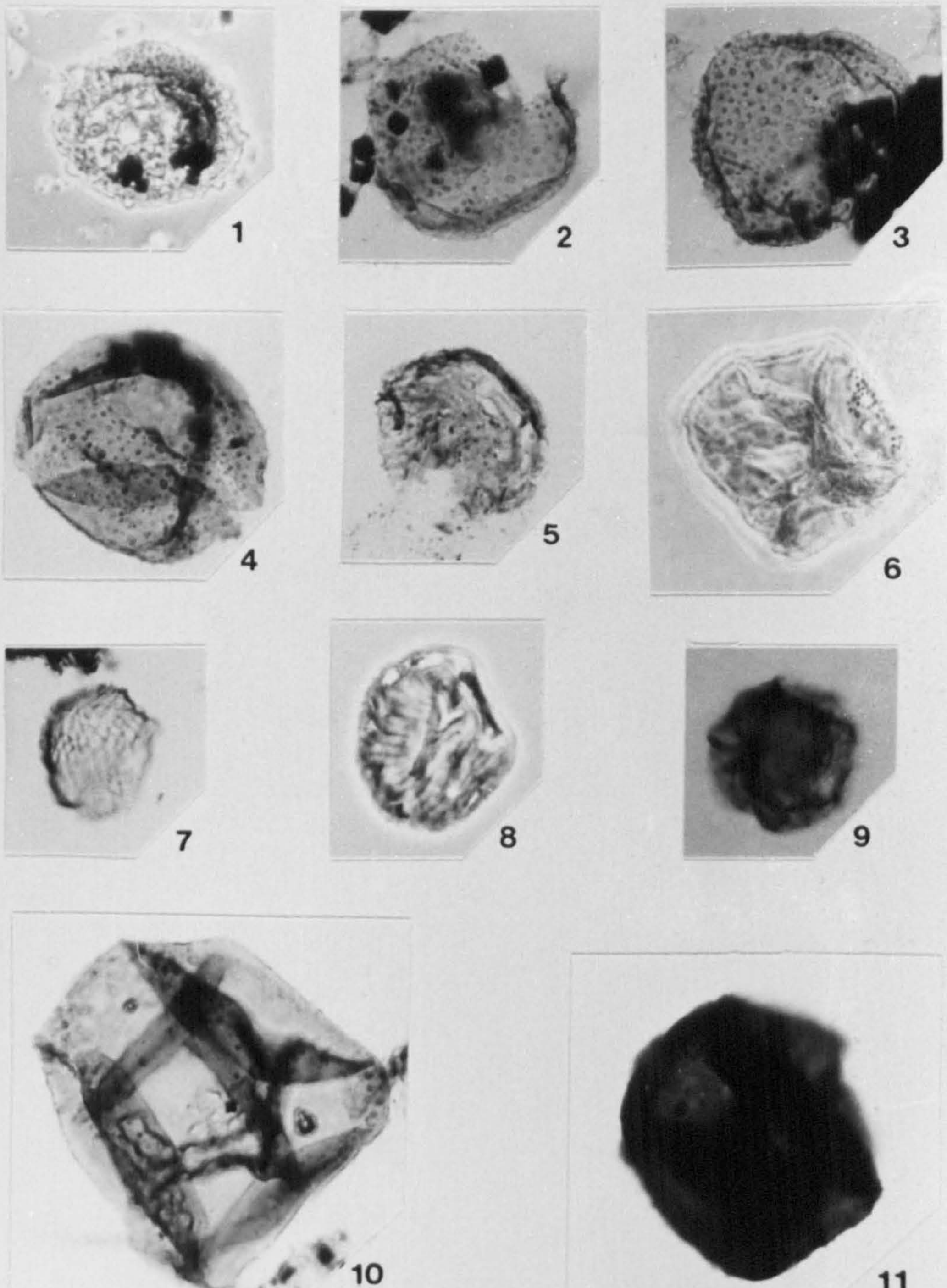


PLATE 15

Magnifications x500 unless otherwise stated

Figure

1-4. *Schismatosphaeridium longhopensis* Dorning 1981a

1. MPA 28412, F2, O44
2. VC/PS 3, F2, O39/4
3. MPA 26080, F1, T41/3
4. MPA 26080, F1, R38/2

5-9. *Schismatosphaeridium rugulosum* Dorning 1981a

5. MPA 28476, F1, D38
6. MPA 26058, F1, R40/4
7. MPA 26058, F1, L31/4
8. MPA 26083, F1, R39/1
9. MPA 28483, F1, T29/2

10-11. *Schismatosphaeridium papillatum* sp.nov.

10. holotype, MPA 26076, F1, U44/4
11. MPA 26077, F2, M35/3

PLATE 15

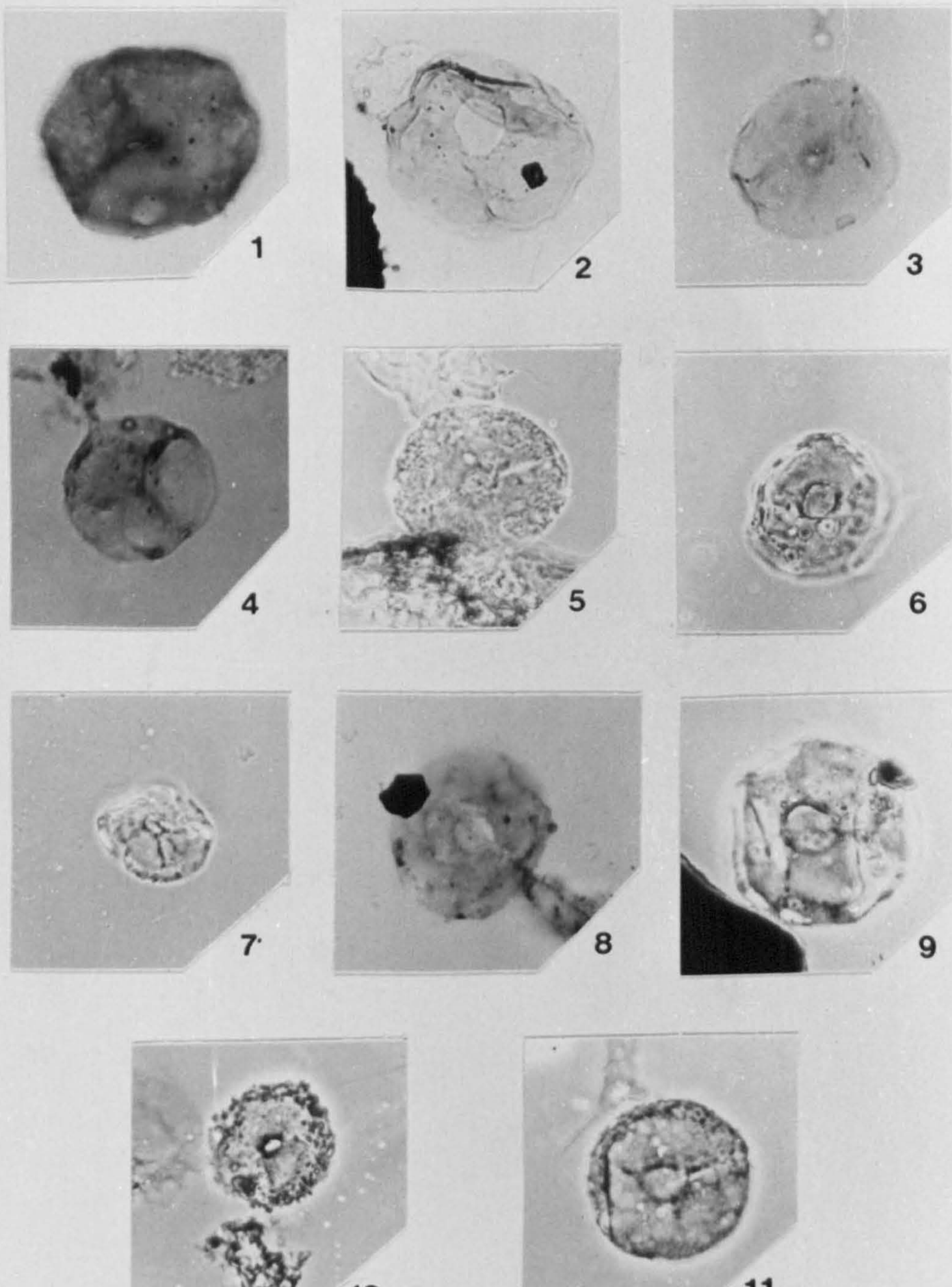


PLATE 16

Magnifications x500 unless otherwise stated

Figure

1-3. Ammonidium gracilis sp.nov.

1. holotype, MPA 26057, F2, H39/3
2. MPA 26078, F1, Q45/2
3. MPA 28416, F2, P47/4

4. Ammonidium waldronense (Tappan & Loeblich 1971) Dorning 1981a

4. MPA 28415, F1, R39/4 (x300)

5-6. Ammonidium granulosum sp.nov.

5. VC/PS 13, F2, V50/2 (x1000)
6. holotype, VC/PS 12, F1, X49/4 (x1000)

7-8. Ammonidium microcladum (Downie 1963) Lister 1970

7. VC/PS 12, F1, V35/3 (x750)
8. VC/PS 8, C3, Q45/3 (x750)

9-10. Ammonidium palmitella (Cramer & Diez 1972a) Dorning 1981a

9. OER/4, F1, R41
10. VC/PS 3, F2, V34/3

11. Cymbosphaeridium gueltaense (Jardiné et al. 1974) Dorning 1981a

11. MPA 28482, F1, H48/2

PLATE 16

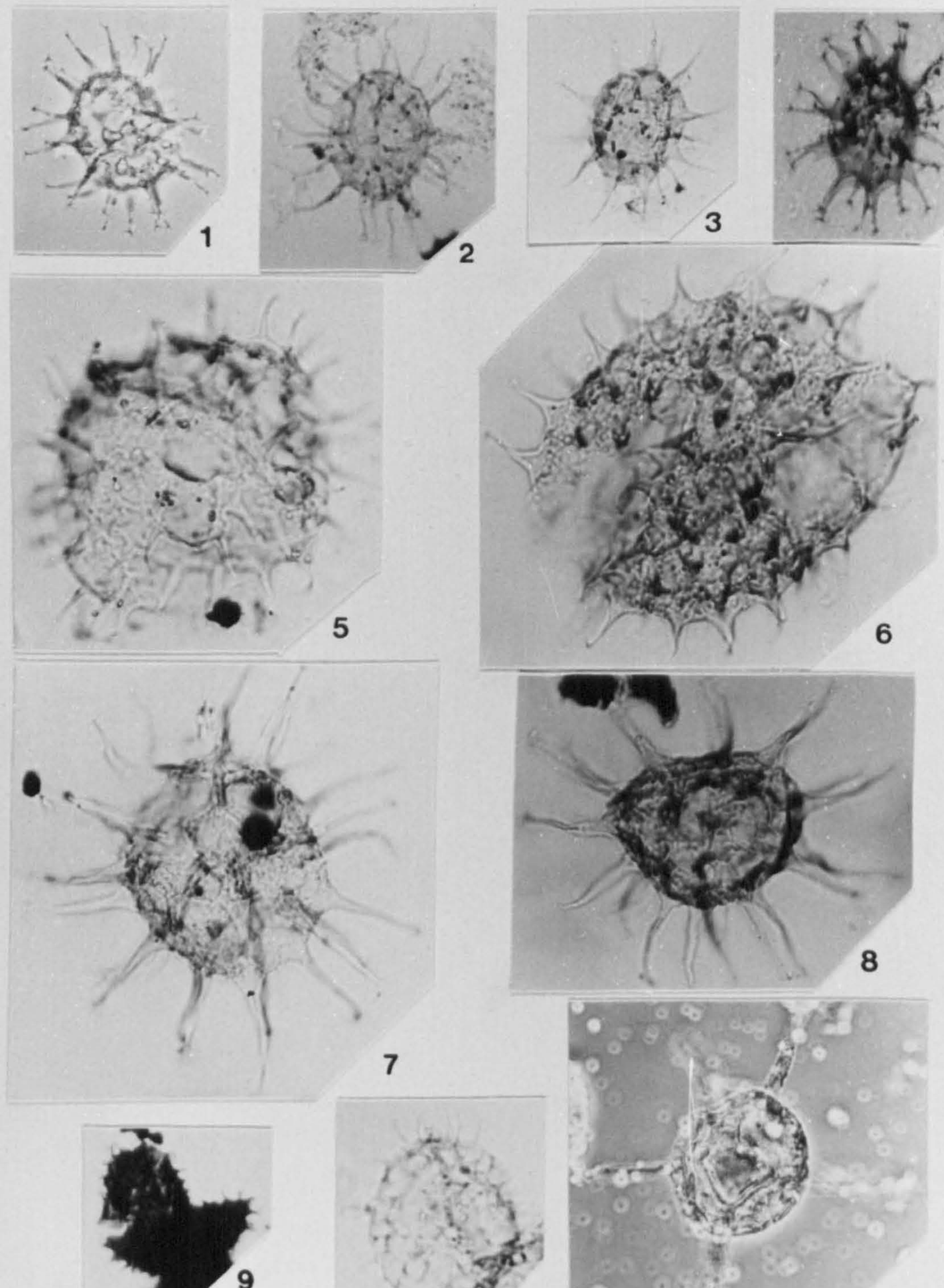


PLATE 17

Magnifications x500 unless otherwise stated

Figure

1. *Cymbosphaeridium gueltaense* (Jardiné *et al*. 1974) Dorning 1981a
   1. MPA 28481, F1, H48/2

2,3. *Cymbosphaeridium* cf. *eurnes* (Cramer & Diez 1972a) Dorning 1981a
   2. MPA 26083, F2, H41/4
   3. MPA 26083, F2, G38/1

4. *Cymbosphaeridium ravum* (Downie 1963) Dorning 1981a
   4. MPA 26070, F2, M37/3

5,8. *Eisenackidium wenlockensis* Dorning 1981a
   5. MPA 26047, F1, U47
   8. MPA 26047, F1, U47

6-7. *Dateriocradus algerensis* (Cramer & Diez 1972a) Dorning 1981a
   6. MPA 26083, F2, P45/2
   7. WCA/PS 3, F1, S55/2

9. *Elektoriskos williereae* (Deflandre & Deflandre-Rigaud 1965) Vanguestaine 1979
   9. MPA 28416, F2, J49/2

10-11. *Dateriocradus monterossae* (Cramer 1969a) Dorning 1981a
   10. MPA 26050, F1, M49/3
   11. MPA 26049, F1, K47/4

12. *Florisphaeridium* cf. *gulletum* Dorning & Hill '1991' (in press)
   12. MPA 26058, F1, P47/2

PLATE 17

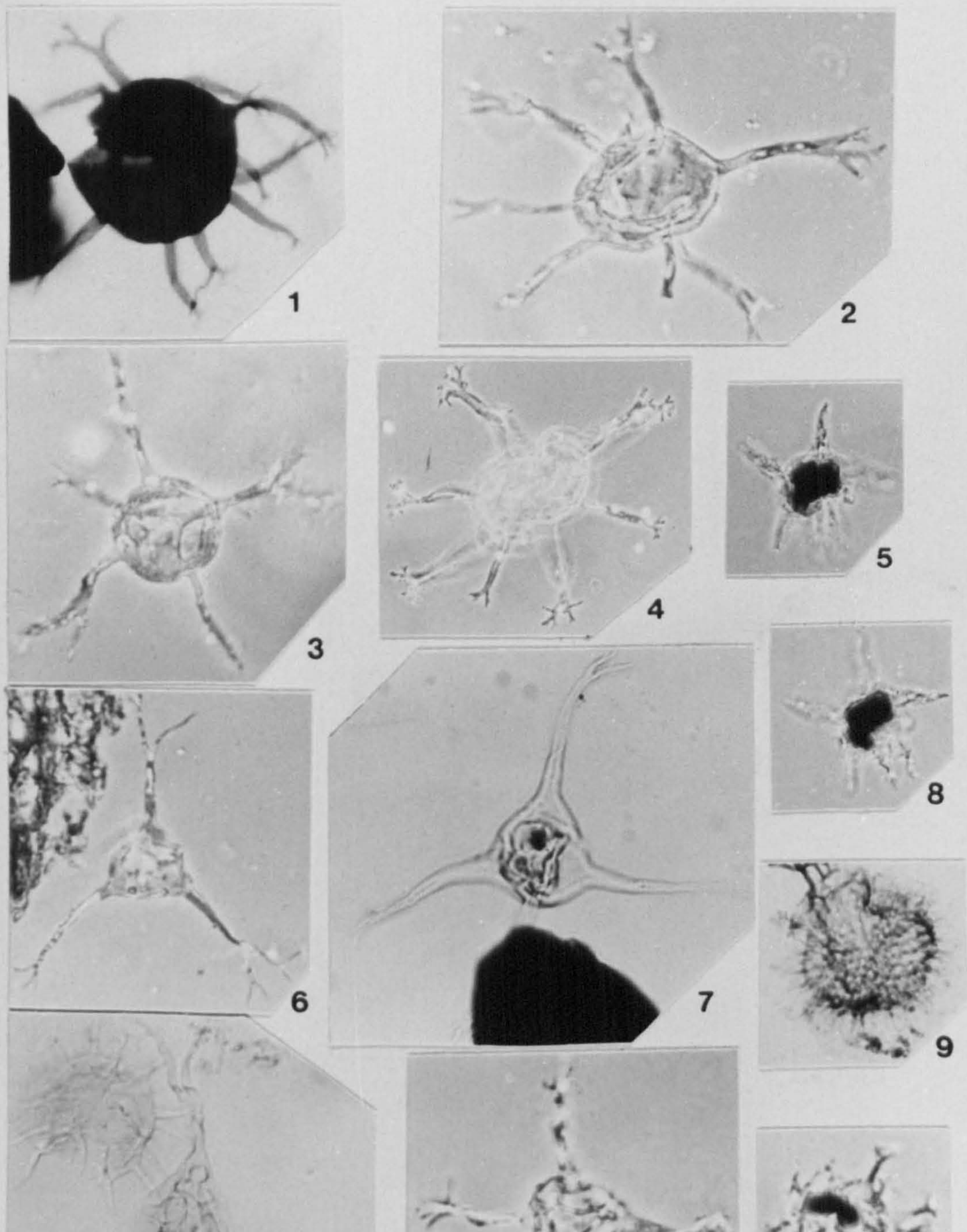


PLATE 18

Magnifications x500 unless otherwise stated

Figure

1. *Elektoriskos williereae* (Deflandre & Deflandre-Rigaud) Vanguestaine 1979
   1. VC/PS 10, F1, V51 (x1000)

2,5. *Florisphaeridium wenlockensis* Dorning 1981a
   2. WC/PS 12, F1, K44/2 (x750)
   5. WC/PS 10, F1, J52 (x750)

3,6,10. *Florisphaeridium gulletum* Dorning & Hill 1989 emend.
   3. MPA 26055, F2, V44/2
   6. MPA 26055, F2, H39
   10. MPA 26052, F1, P38/3

7,11,12. *Gorgonisphaeridium succinum* Lister 1970
   7. VC/PS 3, F2, F46
   11. WC/PS 7, F2, H36/1
   12. MPA 26057, F2, O36

4,8-9. *Gracilisphaeridium encantador* (Cramer 1970) Eisenack *et al*. 1973
   4. MPA 26084, F1, T45/2 (short processed form)
   8. MPA 28415, F2, M36/4 (short processed form)
   9. MPA 28415, F1, K44/4 (long processed form)

13-14. *Leptobrachion* cf. *longhopense* Dorning 1981a
   13. MPA 26057, F2, N35/1
   14. MPA 26057, F2, R49/3

PLATE 18

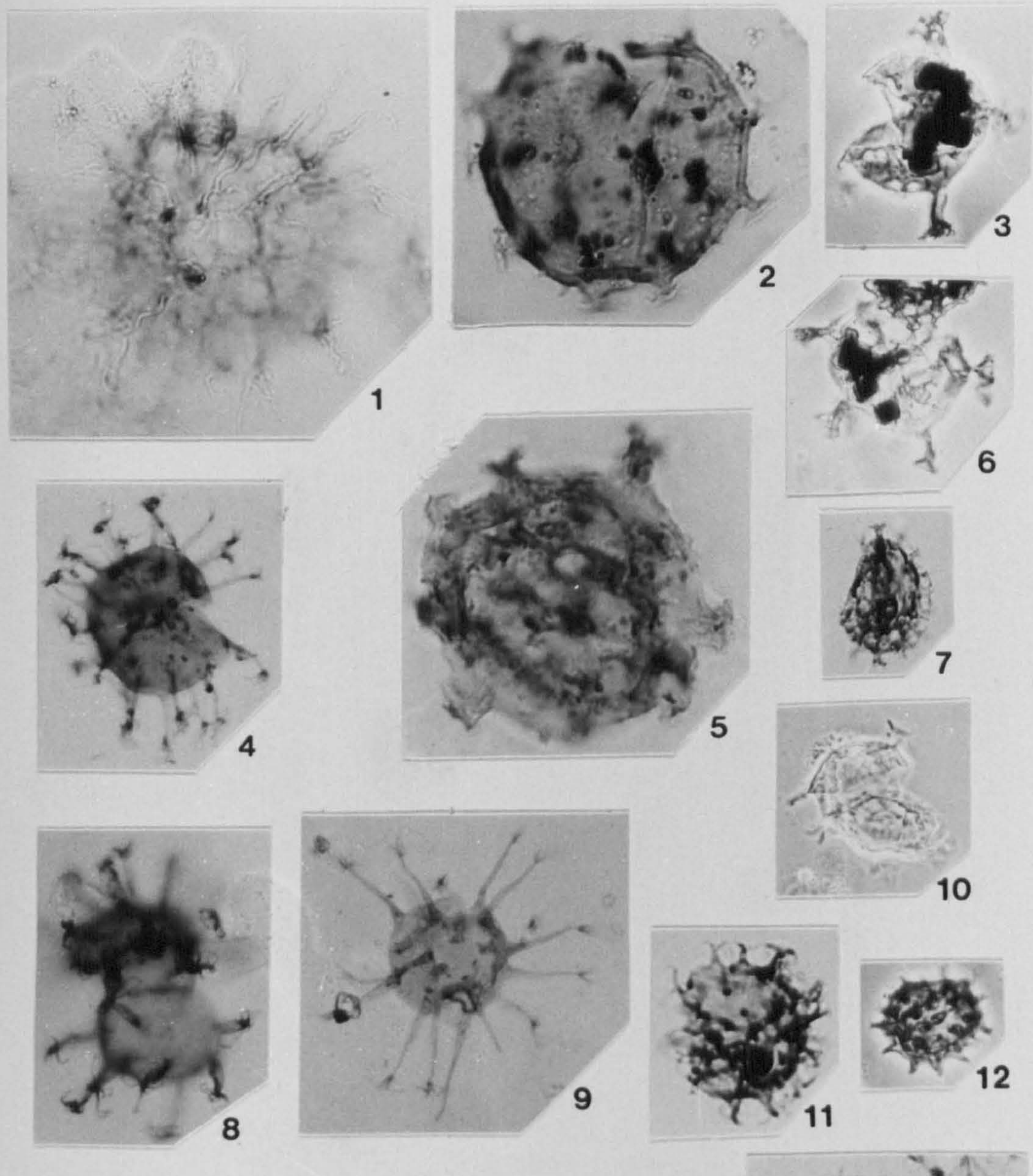


PLATE 19

Magnifications x500 unless otherwise stated

Figure

1,2. *Hoegklintia ancyrea* (Cramer & Diez 1972a) Dorning 1981a

1. MPA 28410, C1, E45/1
2. MPA 26049, C1, E44/3

3,4. *Micrhystridium stellatum* Deflandre 1945

3. MPA 26052, F1, O45/3
4. MPA 26080, F1, J29/2

5,6. *Multiplicisphaeridium arbusculum* Dorning 1981a

5. MPA 28415, F1, T40
6. MPA 26061, F1, N35/4

7. *Multiplicisphaeridium rasulii* Dorning & Hill '1990' (in press)

7. MPA 28415, F1, H41/4

8-10. *Multiplicisphaeridium fisherii* (Cramer 1968) Lister 1970

8. VC/PS 13, F2, R54/2
9. MPA 26059, F1, V35/1
10. MPA 26046, F1, V38/3

PLATE 19

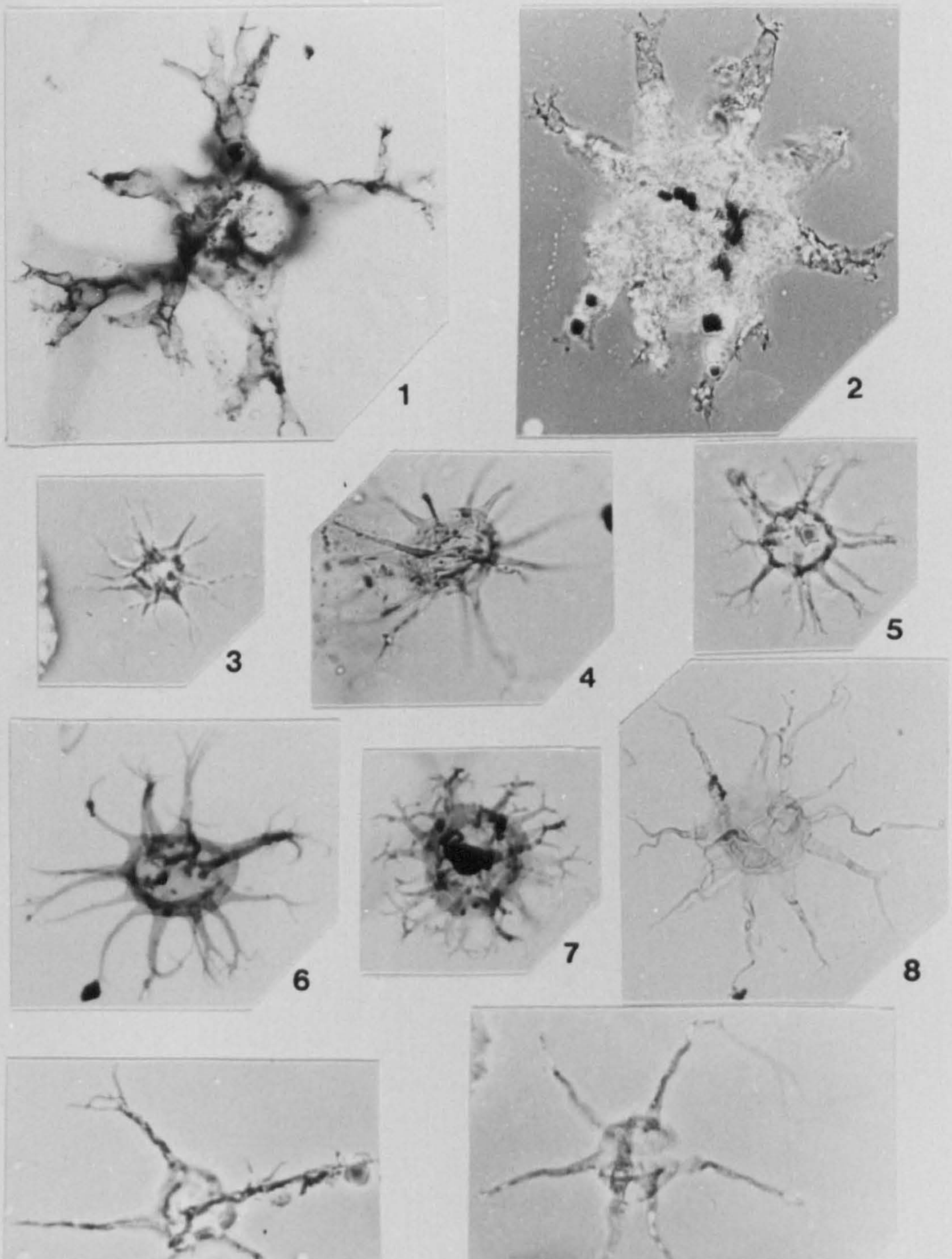


PLATE 20

Magnifications x500 unless otherwise stated

Figure

1-3. *Multiplicisphaeridium* sp. A

1. BR/PS 9, 2, V47/2
2. MPA 28477, F1, L44
3. MPA 28416, F1, R33/2

4,6. *Oppilatala eoplanktonica* (Eisenack 1955) Dorning 1981a emend.

4. MPA 26061, F2, J43/1
6. MPA 28474, F2, G40/2

5. *Oppilatala frondis* (Cramer & Diez 1972a) Dorning 1981a

5. BR/PS 9, 2, L36

7,9,10. *Oppilatala smelrorii* sp.nov.

7. holotype, MPA 26059, F1, V38/2
9. BR/PS 6, 4, T34/2
10. BR/PS 9, 1, V41/4

8. *Oppilatala insolita* (Cramer & Diez 1972a) Dorning 1981a

8. VC/PS 10, F1, U53/2

11-12. *Oppilatala ramusculosa* (Deflandre 1945) Dorning 1981a

11. VC/PS 9, F1, U44/2
12. MPA 26070, F2, H41/4

PLATE 20

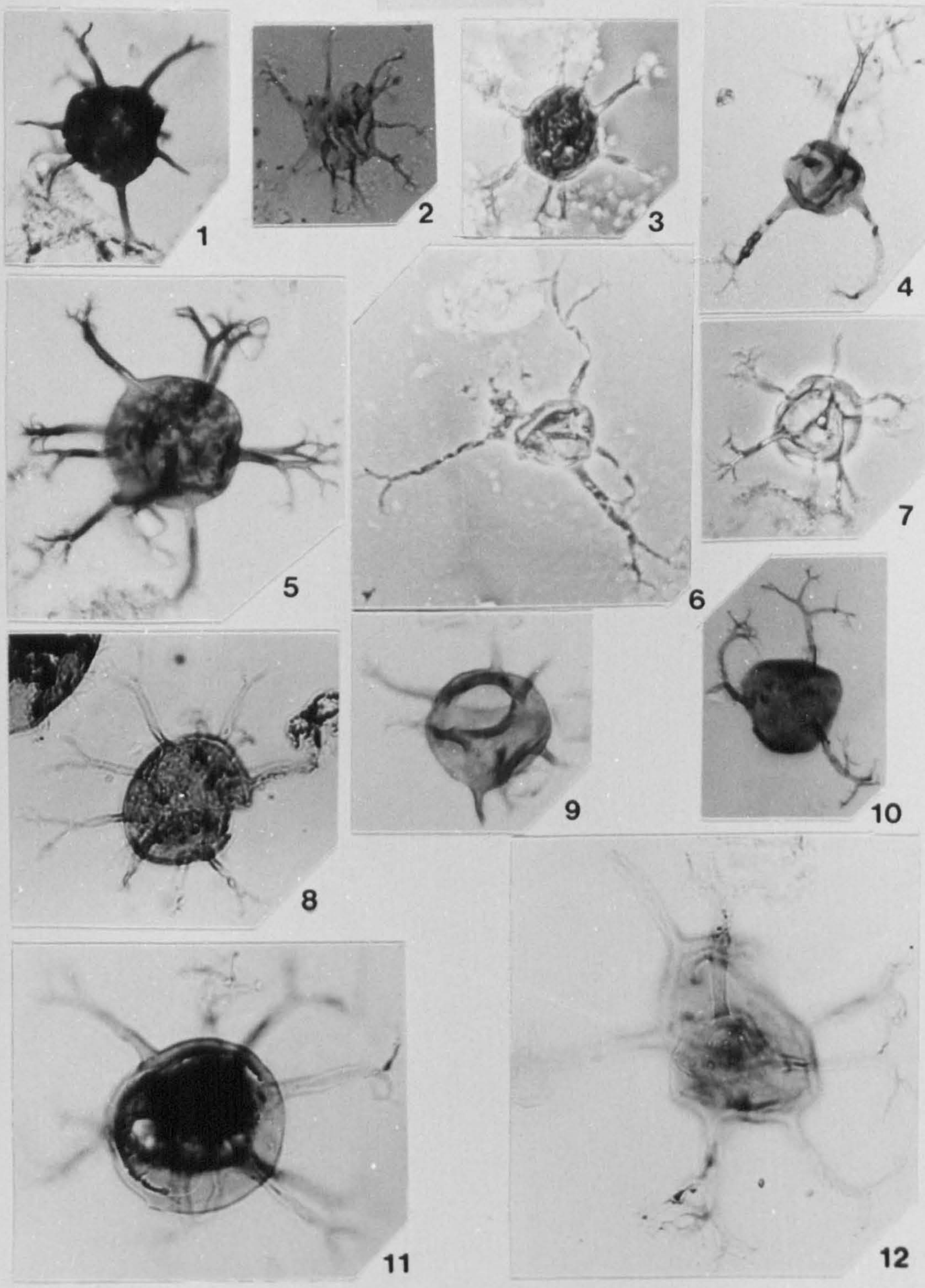


PLATE 21

Magnifications x500 unless otherwise stated

Figure

1-2. Salopidium granuliferum (Downie 1959) Dorning 1981a

1. VC/PS 13, F2, V50/2 (x1000)
2. VC/PS 11, F1, K38/1 (x1000)

3-5. Salopidium priewalderae sp.nov.

3. VC/PS 3, F2, S49/2
4. MPA 26076, F1, H42/4
5. holotype, MPA 26076, F1, U38/2

6,9,11. Salopidium whitwellensis sp.nov.

6. holotype, WC/PS 5, F2, S41/3
9. VC/PS 5, F2, O48/2
11. VC/PS 12, F2, O49/3

7,8,10. Salopidium truncatum sp.nov.

7. holotype, MPA 26073, F1, E50/1
8. MPA 26072, F1, N40
10. MPA 26072, F1, L43/2

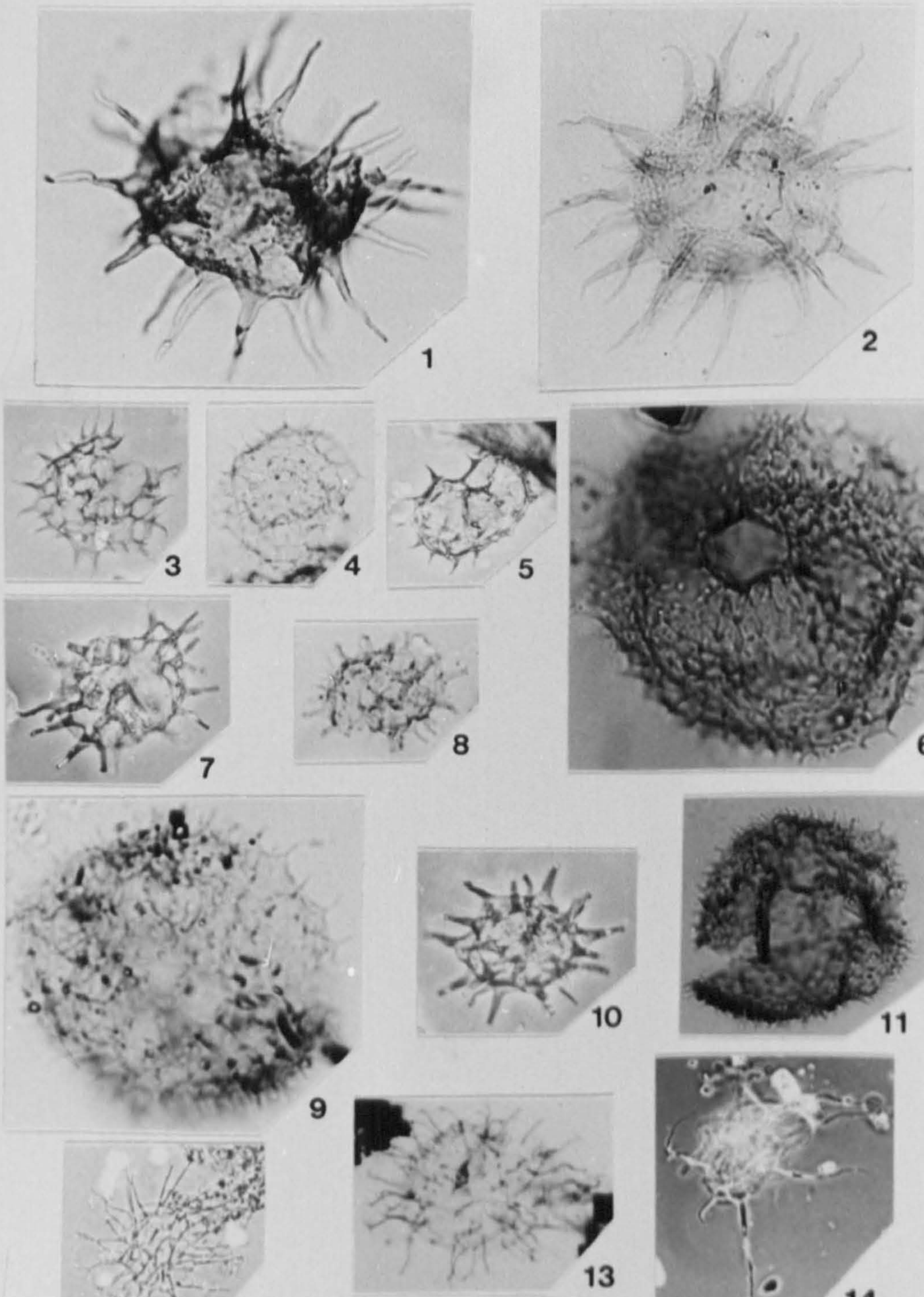
12-13. Tunisphaeridium parvum Deunff & Evitt 1968

12. MPA 26063, F2, U37/2
13. MPA 26049, F1, V37/4

14. Salopidium woolhopensis Dorning 1981a

14. MPA 26083, F1, V49

PLATE 21



12-14. *Visbysphaera dilatispinosa* (Downie 1963) Lister 1970

12. BR/PS 9, 2, F49/4

13. MPA 28415, F1, M37/3

14. MPA 28412, F1, D41/3

PLATE 22

Magnifications x500 unless otherwise stated

Figure

1. *Tunisphaeridium parvum* Deunff & Evitt 1968
   1. VC/PS 10, F1, E53/4

2. *Tunisphaeridium tentaculiferum* (Martin 1966) Cramer 1970
   2. VC/PS 5, F1, N38/1

3. *Estiastra barbata* Downie 1963
   3. MPA 28411, F1, R41

4-6. *Tylotopalla caelamenicutis* Loeblich 1970
   4. MPA 26063, F2, O48/1
   5. MPA 26058, F1, T39/1
   6. MPA 26058, F1, K44/1

7,9. *Tylotopalla* cf. *cellonensis* Priewalder 1987
   7. MPA 26080, F1, S37
   9. MPA 26066, F1, R45

8. *Tylotopalla robustispinosa* (Downie 1959) Eisenack *et al*. 1973
   8. MPA 26080, F1, Q42/4

10. *Tylotopalla wenlockia* Dorning 1981a
   10. MPA 26073, F1, X51/1

11. *Visbysphaera* cf. *dudleyspinosa* Dorning & Hill '1991' (in press)
   11. MPA 26062, F2, U48/4

PLATE 22

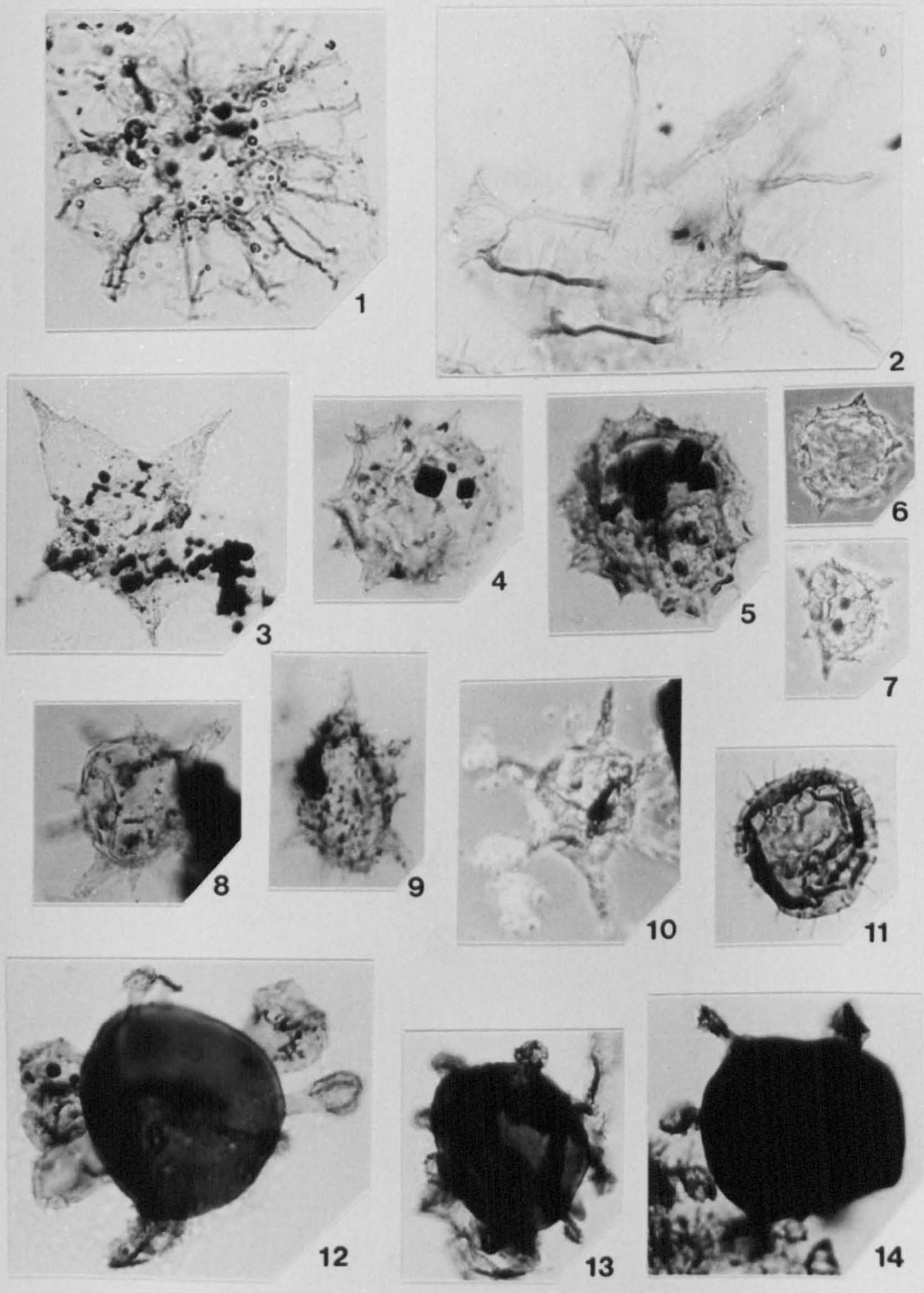


PLATE 23

Magnifications x500 unless otherwise stated

Figure

1. *Visbysphaera* cf. *dudleyspinosa* Dorning & Hill '1991' (in press)
   1. VC/PS 3, F2, Q45/5

2,3,7. *Visbysphaera gotlandica* (Eisenack 1954) Lister 1970
   2. MPA 26084, F1, J33/2
   3. VC/PS 2, F1, H37/1 (x1000)
   7. MPA 28476, F1, K37/1

4-6. *Visbysphaera meson* (Eisenack 1954) Lister 1970
   4. VC/PS 8, C3, S39/2 (x1000)
   5. VC/PS 13, F2, Q57/3 (x1000)
   6. MPA 26083, F1, T40/3

8-11. *Visbysphaera filosa* sp.nov.
   8. VC/PS 10, F1, N46/3 (x1000)
   9. MPA 26084, F1, G51/1
   10. MPA 26076, F1, N46/2
   11. VC/PS 8, F1, P46/2

12. *Visbysphaera oligofurcata* (Eisenack 1954) Lister 1970
   12. MPA 26066, F1, Q42/1

PLATE 23

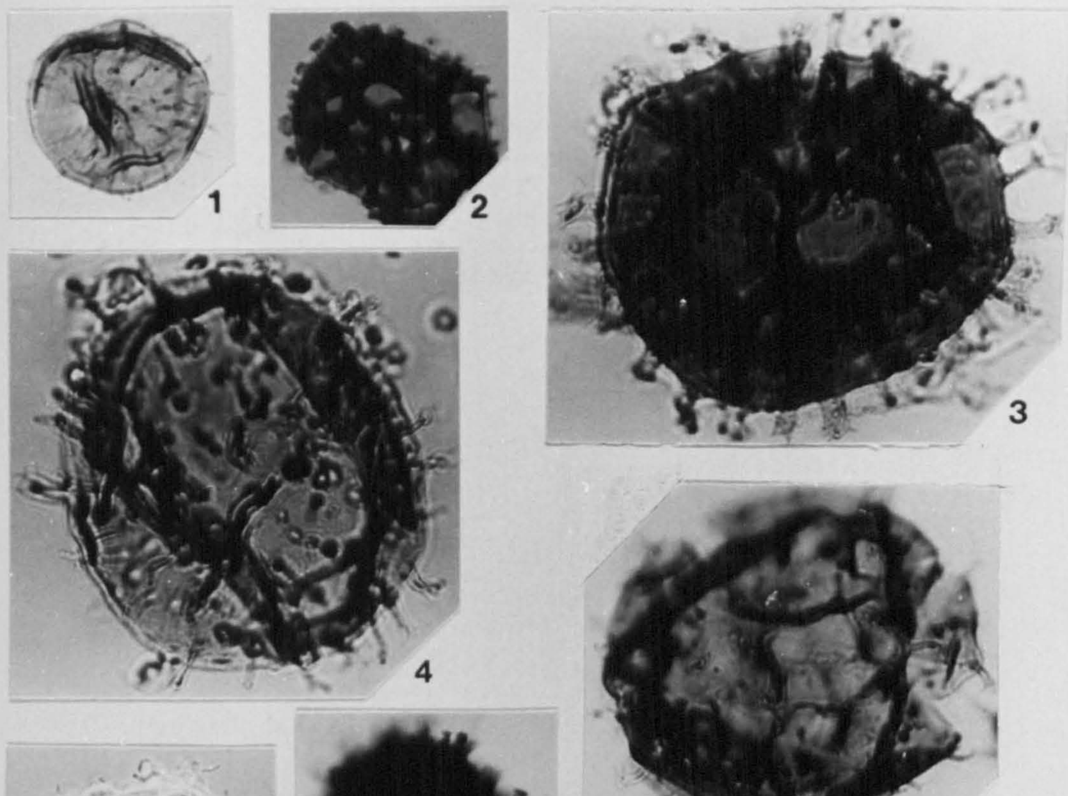


PLATE 24

Magnifications x1000 unless otherwise stated

Figure

1. *Visbysphaera oligofurcata* (Eisenack 1954) Lister 1970
   1. WC/PS 5, F1, K46/3

2-4. *Visbysphaera varispinosa* Dorning & Hill '1991' (in press)
   2. WC/PS 13, F1, P49
   3. WC/PS 8, F1, Q48/1
   4. WC/PS 8, F1, Q48/1

5-6. *Visbysphaera* sp.A
   5. WC/PS 9, F1, M42
   6. MPA 26084, F1, J33/2

PLATE 24

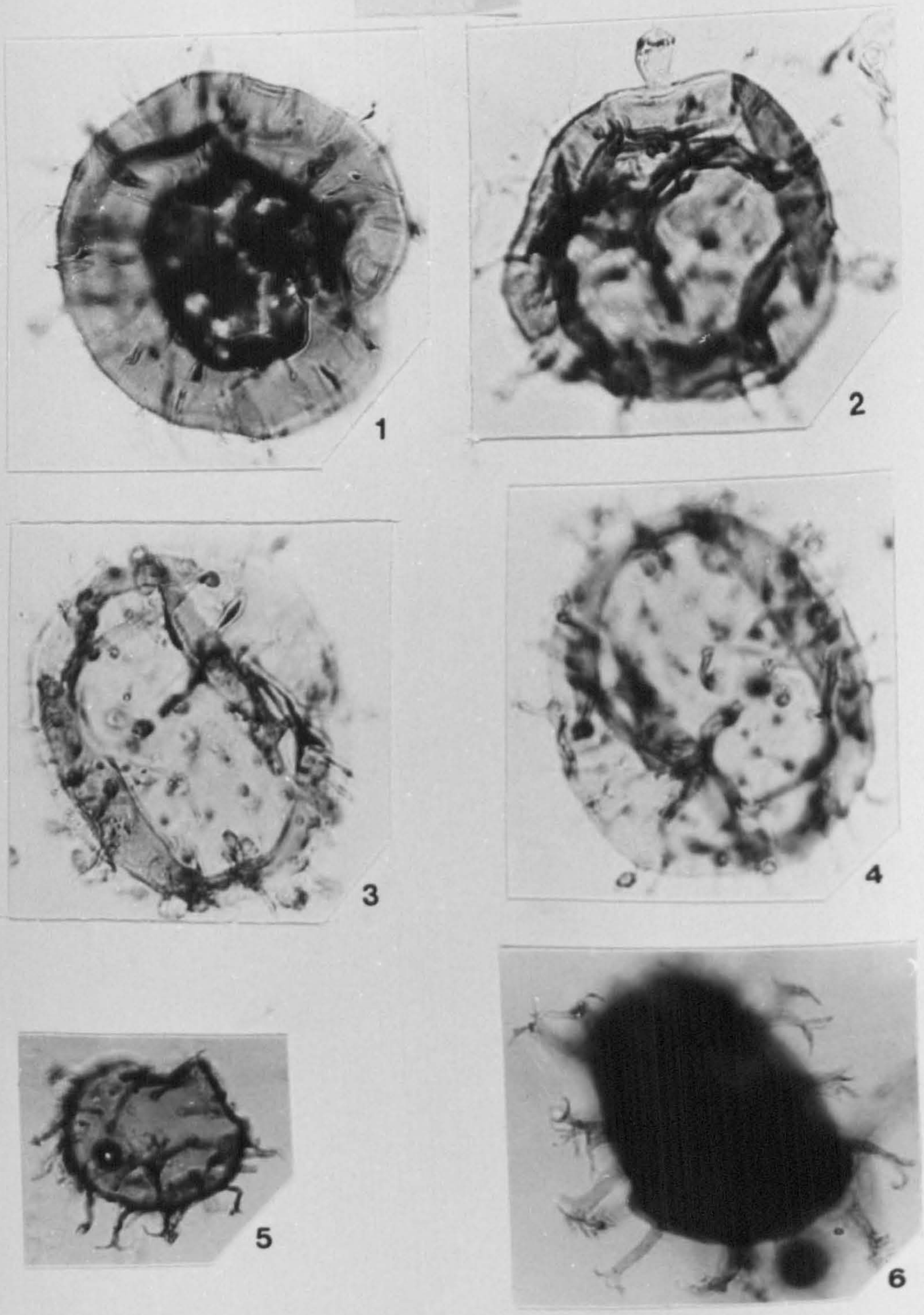


PLATE 25

Magnifications x500 unless otherwise stated

Figure

1-2. *Estiastra granulata* Downie 1963
1. MPA 26050, C1, Q38/4 (x200)
2. MPA 26050, C1, M50/1 (x200)

3,5. *Onondagaella* cf. *asymmetrica* (Deunff 1955) Cramer 1966c emend. Playford 1977
3. WC/PS5, F1, W41/4 (x750)
5. MPA 26054, F1, S38/2

4. *Pulvinosphaeridium* cf. *oligospinosum* (Eisenack 1934) Eisenack 1954
4. MPA 28416, F1, U42

6,10,11. *Veryhachium trispinosum* Formgroup (Eisenack 1938) Deunff 1954 *ex* Downie 1959
6. MPA 26081, F1, K41
10. MPA 26081, F1, O44/2
11. MPA 26076, F1, P50/3

7. *Pulvinosphaeridium pulvinellum* Eisenack 1954
7. WC/PS 11, F1, R52/2

8-9. *Fractoricoronula checkleyensis* (Dorning 1981a) n. comb.
8. MPA 26076, F1, E47/1
9. MPA 28411, F2, E50/4

12. *Veryhachium rhomboidium* Downie 1959 emend. Turner 1984
12. MPA 26054, F1, P48/4

PLATE 25

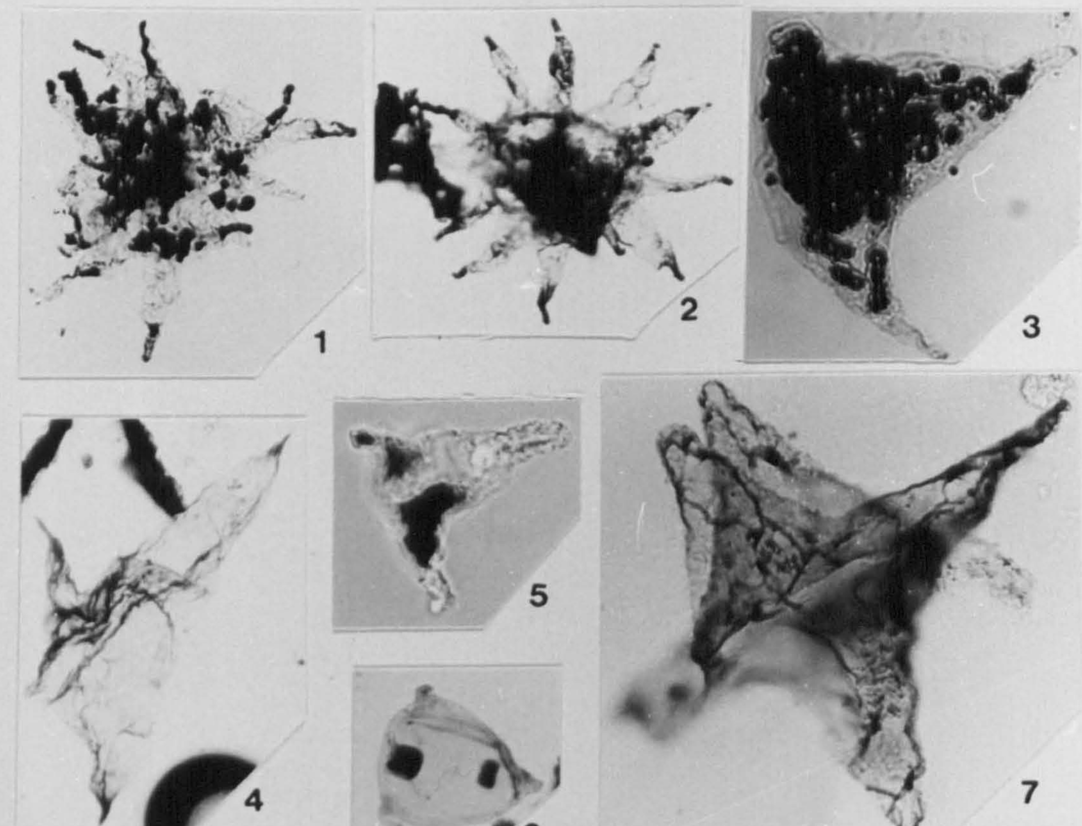


PLATE 26

Magnifications x500 unless otherwise stated

Figure

1,3. Veryhachium wenlockium Formgroup (Downie 1959) Downie & Sarjeant 1964

1. MPA 26058, F1, J45
3. WC/PS 10, F1, O51/4

2. Veryhachium lairdii (Deflandre 1946) Deunff 1959 ex Downie 1959

2. MPA 26077, F1, P32/1

4,5,9,10. Ambitisporites dilutus (Hoffmeister 1959) Richardson & Lister 1969

4. MPA 26058, F1, U37
5. MPA 26076, F1, P39/3
9. MPA 28410, F1, R41/1
10. WCA/PS 2, F1, Q29 x1000

6. Alveosphaera cf. coarctata Kirjanov 1978

6. WC/PS 2, F2, C39/2

7. Plant cuticle

7. MPA 28480, C1, K35/1

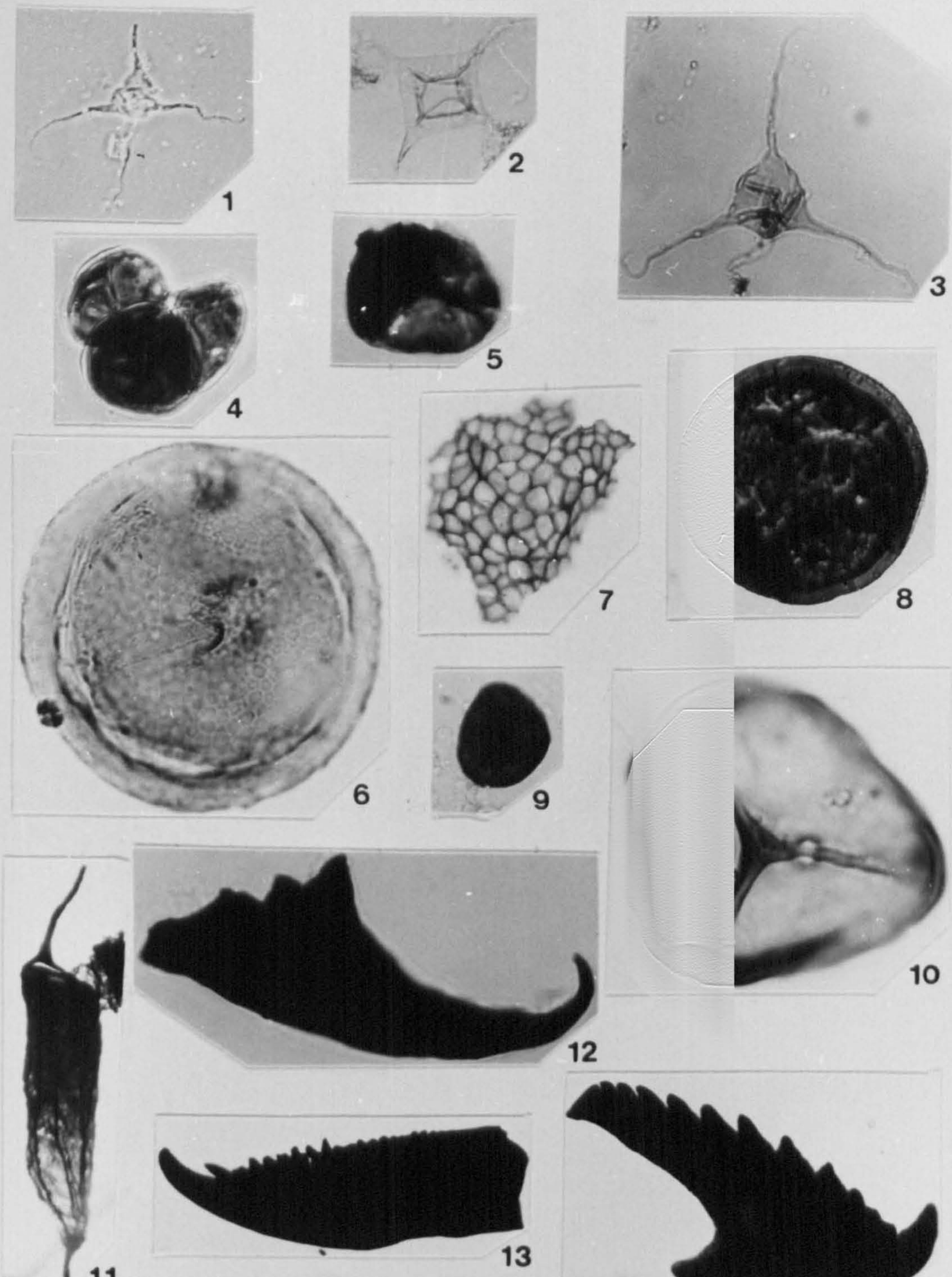
8. Tasmanites cf. medius Eisenack 1931

8. WC/PS 8, F1, K41/2

11. Graptolite prosicula

11. MPA 28416, C2, V49/2

PLATE 26



16-18. _Cymatiosphaera pentagonalis_ Kirjanov 1978

16. MPA 26060, F1, M50/1
17. MPA 26060, F1, M42/1
18. MPA 26059, F2, H38/3

19. _Dictyotidium dictyotum_ (Eisenack 1938) Eisenack 1955a

19. MPA 28485, F1, K47/2

20. _Dictyotidium_ cf. _cavernosulum_ Playford 1977

20. MPA 26076, F1, Q43/1

21. _Dictyotidium stenodictyum_ Eisenack 1965a

21. MPA 26081, F1, N38/3

PLATE 27

Magnifications x500 unless otherwise stated

Figure

1-3. *Cymatiosphaera fragilis* sp.nov.

1. MPA 26081, F1, S37/4
2. MPA 26077, F2, G46/2
3. MPA 26070, F2, L36/3

4-6. *Cymatiosphaera gorstia* Dorning 1981a

4. MPA 26080, F1, R46
5. MPA 28415, F1, L44/4
6. MPA 26076, F1, O37/1

7,8. *Cymatiosphaera heloderma* Cramer & Diez 1972a

7. MPA 26057, F2, G46/4
8. MPA 26084, F3, L34/4

9,10. *Cymatiosphaera octoplana* Downie 1959

9. MPA 26058, F1, R49
10. VC/PS 2, F2, S45

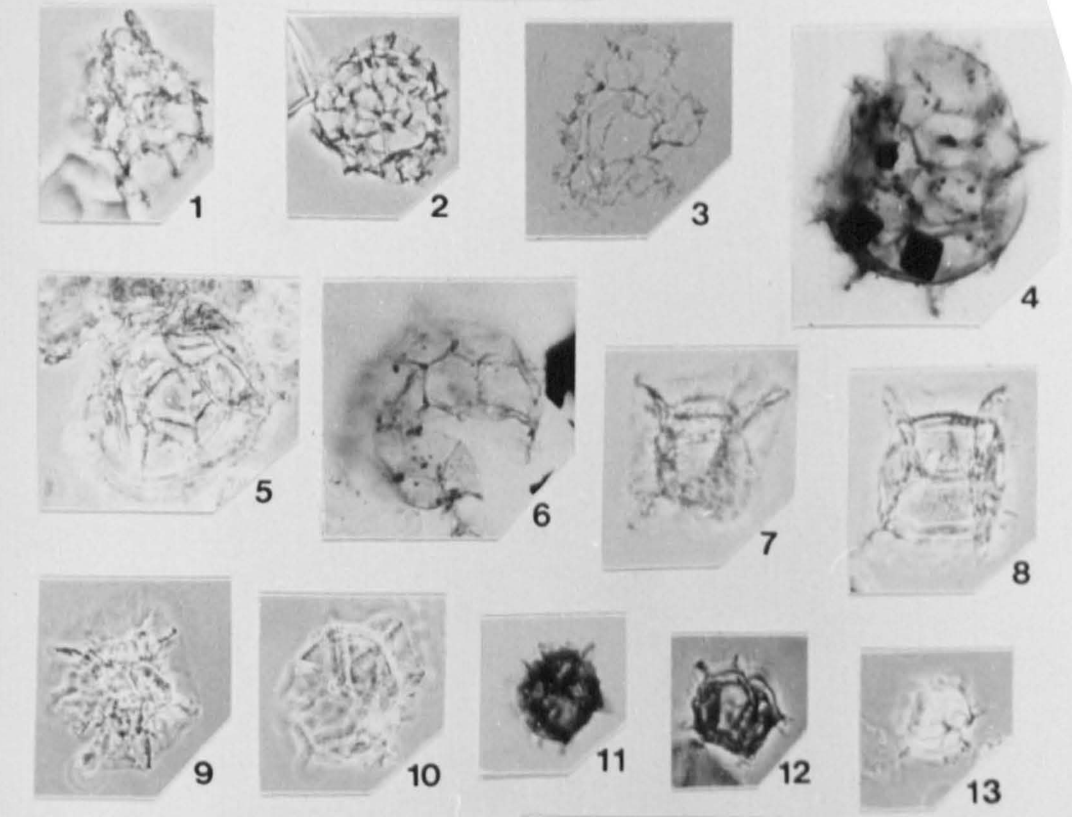
11-13. *Cymatiosphaera pavimenta* (Deflandre 1945) Deflandre 1954

11. MPA 26077, F2, R40
12. MPA 26066, F1, R33/2
13. MPA 26076, F1, U41/1

14,15. *Cymatiosphaera ledburica* Dorning 1981a

14. MPA 26074, F1, R38/3
15. MPA 26059, F1, E32

PLATE 27



14-16. _Domasia trispinosa_ Downie 1960

14. MPA 26058, F1, O37/3

15. MPA 28416, F2, V50/2

16. BR/PS 2, F1, S44

PLATE 28

Magnifications x500 unless otherwise stated

Figure

1. *Deunffia brevispinosa* Downie 1960
   1. MPA 26084, VF2, O32/1

2,3,11. *Deunffia furcata* Downie 1960
   2. MPA 26077, F2, L48/4
   3. MPA 26080, F1, N31/4
   11. MPA 26080, F1, R33/2

4,6. *Deunffia ramusculosa* Downie 1960
   4. MPA 26084, F1, O54/1
   6. MPA 28410, F1, P36/1

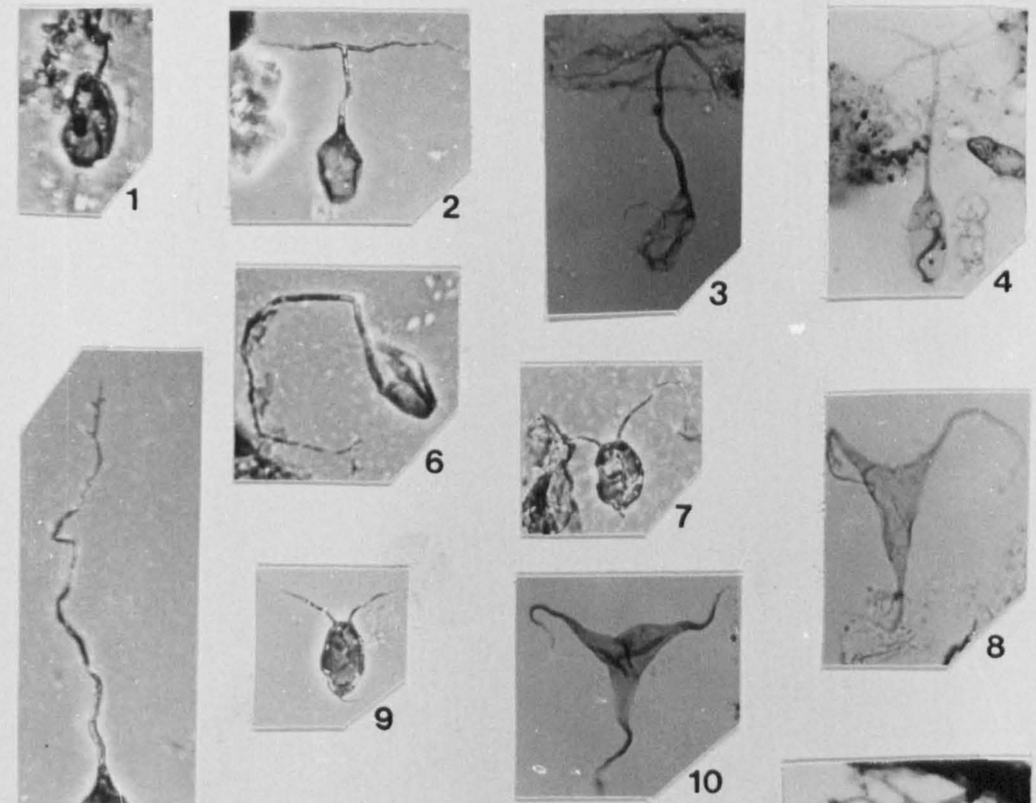
5. *Deunffia monospinosa* Downie 1960
   5. MPA 26084, F1, S48

7,9. *Domasia bispinosa* Downie 1960
   7. MPA 26084, F1, V46
   9. MPA 26084, F1, T53/3

8,10. *Domasia limaciforme* (Stockmans & Willière 1963) Cramer 1970
   8. MPA 26070, F2, M42/4
   10. MPA 26070, F2, L44/4

12,13. *Domasia quadrispinosa* Hill 1974b
   12. MPA 28411, F1, J43
   13. MPA 28415, F1, U39/1

PLATE 28



12. *Pterospermella onodagaensis* (Deunff 1955) Eisenack *et al*. 1973

12. MPA 28479, F2, O41/1

15,18. *Carminella maplewoodensis* Cramer 1968

15. MPA 26049, F1, Q44

18. MPA 26049, F1, L44/3

16. *Dictyotidium* cf. *cavernosulum* Playford 1977

16. MPA 26077, F2, N38

17. *Dictyotidium dictyotum* (Eisenack 1938) Eisenack 1955a

17. VC/PS 8, F1, K46/2

PLATE 29

Magnifications x500 unless otherwise stated

Figure

1. *Eupoikilofusa* cf. *filifera* (Downie 1959) Dorning 1981a
   1. MPA 26080, F1, Q30/3

4. *Leiofusa estrecha* Cramer 1964
   4. VC/PS 8, C3, N49/4

2,3. *Leiofusa tumida* Downie 1959
   2. MPA 26048, F1, S42
   3. MPA 28410, F1, P42

5,6. *Eupoikilofusa striatifera* (Cramer 1964) Cramer 1970
   5. MPA 26059, F1, L48
   6. MPA 26077, F2, E48/2

7. *Geron* sp. A
   7. MPA 28415, F1, H45

8,13. *Pterospermella* sp.A
   8. MPA 26047, F1, V37/3
   13. MPA 26052, F1, Q42/4

9,14. *Duvernaysphaera araneides* (Cramer 1964) Cramer 1972
   9. VC/PS 5, F1, J43
   14. MPA 26084, F1, Q40/4

10,11. *Leiofusa parvitatis* Loeblich 1969
   10. VC/PS 3, F2, P41
   11. VCA/PS 2, F1, M41/2

PLATE 29

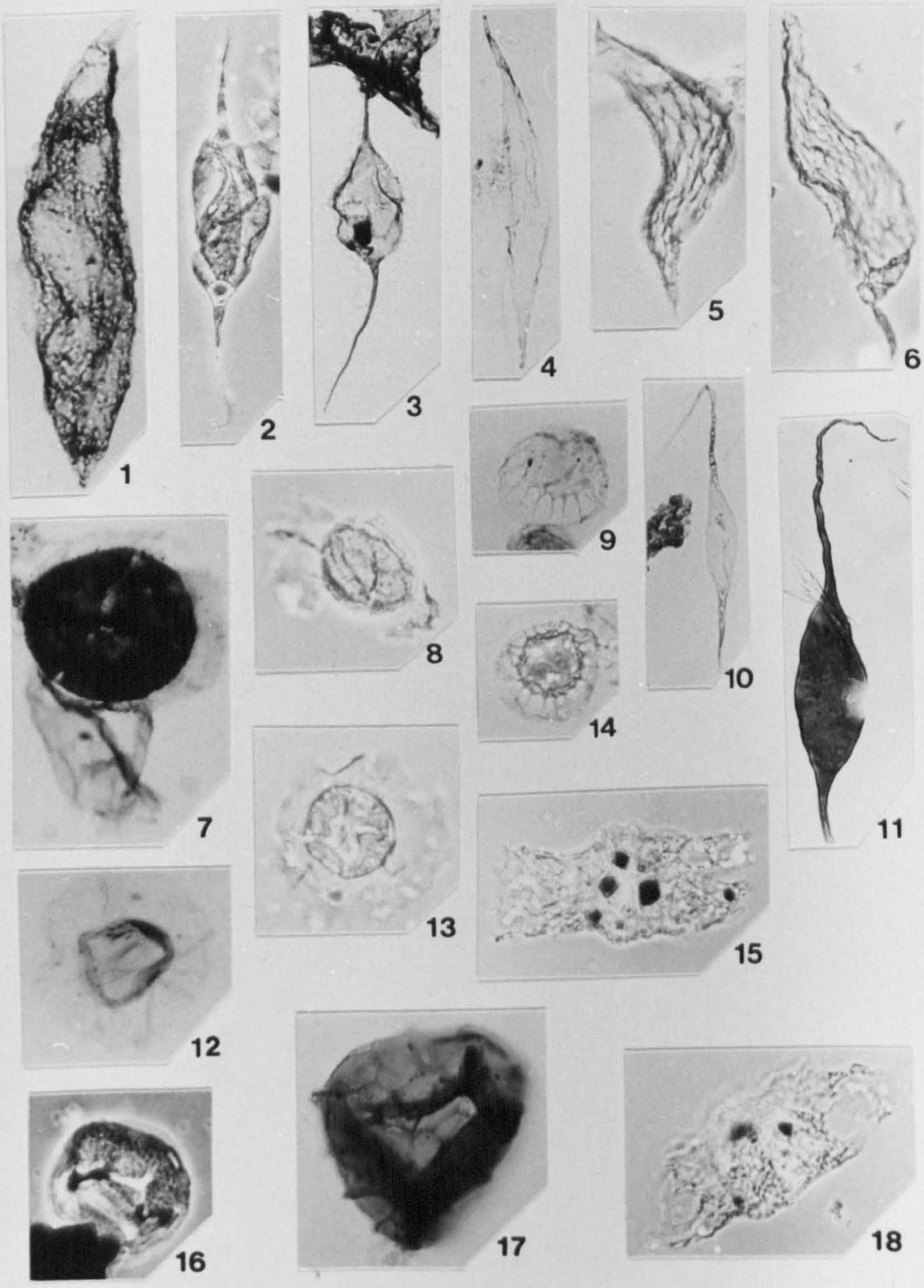


PLATE 30

Magnifications x500 unless otherwise stated

Figure

1. *Leiosphaeridia laevigata* Stockmans & Villière 1963

   1. LRG/PS 1, C1, T44/3

2. *Eupoikilofusa striatifera* (Cramer 1964) Cramer 1970

   2. LRG/PS 2, F1, S32/1

3. *Cymatiosphaera pavimenta* (Deflandre 1945) Deflandre 1954

   3. CLY/PS 1, 3, J35/1

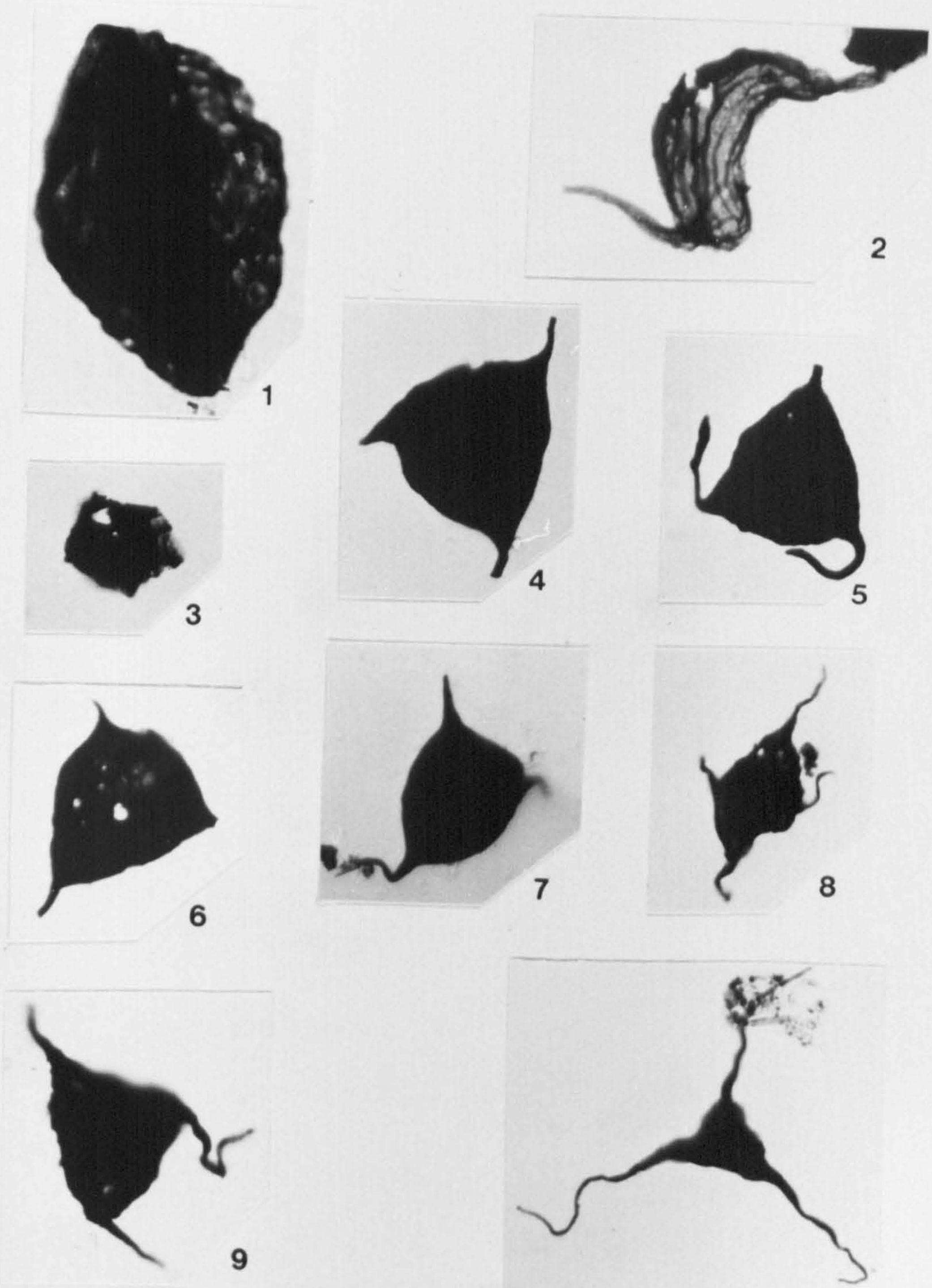
4-7. *Veryhachium trispinosum* Formgroup (Eisenack 1938) Deunff 1954 *ex* Downie 1959

   4. PEN/PS 3, 2, B48
   5. HAF/PS 1, 2, J41
   6. LRG/3, 2, Q35/2
   7. OER/3, 1, R52/2

8-10. *Veryhachium wenlockium* Formgroup (Downie 1959) Downie & Sarjeant 1964

   8. LRG/PS 1, 1, U44/2
   9. CS/PS 3, 1, G32/2
   10. CLY/PS 1, 1, J47/3

PLATE 30



<u>PLATE 31</u>

Magnifications x500 unless otherwise stated

<u>Figure</u>

1-2. <u>Ammonidium microcladum</u> (Downie 1963) Lister 1970

1. LRG/PS 2, 2, G35/4 (x1000)
2. LRG/PS 1, 3, T37/3

3-7. <u>Diexallophasis denticulata</u> (Stockmans & Willière 1963) Loeblich 1970

3. LRG/PS 1, 1, S42/1 (x750)
4. LRG/PS 1, 1, Q43 (x750)
5. OER/ PS 9, F2, L39
6. PEN/PS 3, 4, S47/2
7. CLY/PS 1, 2, V49

7-9. <u>Micrhystridium</u> sp.

7. CLY/PS 1, 2, K39/3
8. OER/PS 3, 2, M46
9. LRG/PS 2, 2, S42/2 (x750)

PLATE 31

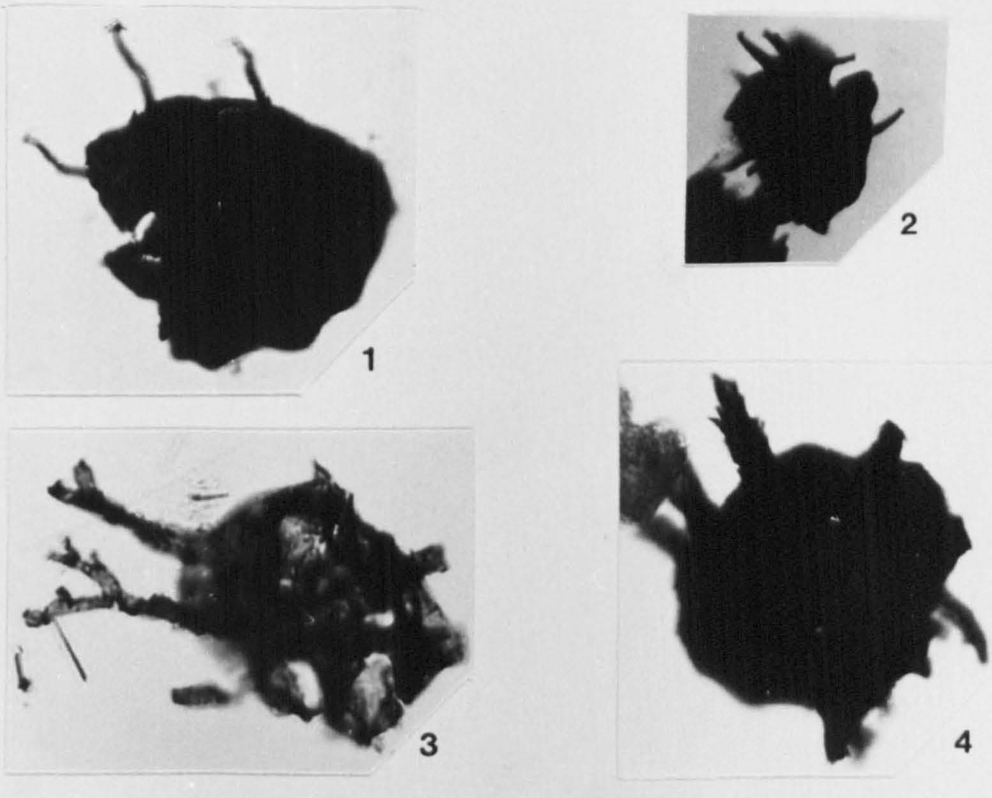


PLATE 32

Magnifications x500 unless otherwise stated

Figure

1-3. *Multiplicisphaeridium* cf. *arbusculum* Dorning 1981a

1. CS/PS 5, 1, S35/1
2. HAF/PS 1, 1, T43/1
3. CS/PS 2, 2, P34/2

4. *Oppilatala* cf. *eoplanktonica* (Eisenack 1955a) Dorning 1981a

4. LRG/2, 2, H23/2 (x750)

5. *Oppilatala* sp.

5. PEN/PS 3, 2, J42/4 (x750)

6. *Salopidium woolhopensis* Dorning 1981a

6. CS/PS 6, 3, N35/4 (x750)

7. *Tylotopalla caelamenicutis* Loeblich 1969

7. CS/PS 3, 3, M40/4

8. *Salopidium* sp.

8. LRG/2, 2, N47/3

9. *Tylotopalla wenlockia* Dorning 1981a

9. LRG/2, 2, F33/4 (x750)

PLATE 32

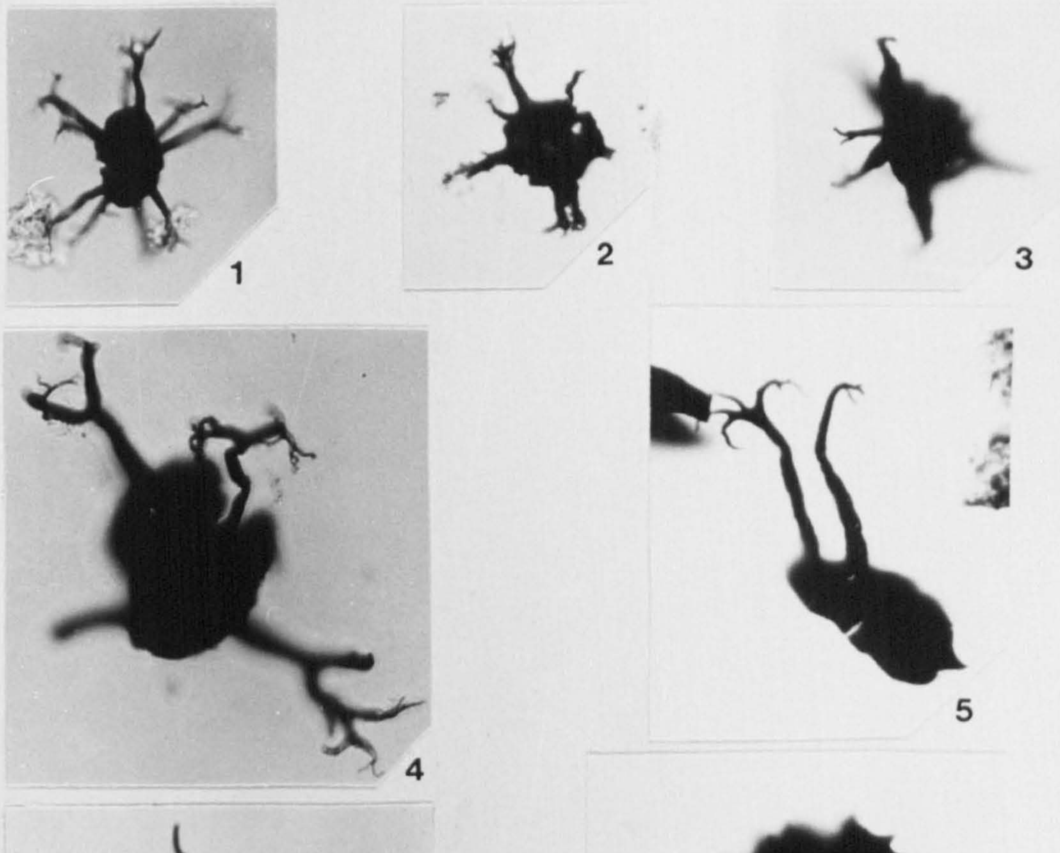


PLATE 33

Magnifications x500 unless otherwise stated

Figure

1. Tylotopalla wenlockia Dorning 1981a
   1. LRG/PS 2, 2, K28/2 (x750)

2,3. Visbysphaera cf. meson (Eisenack 1954) Lister 1970
   2. OER/PS 3, 2, J49/3
   3. LRG/PS 3, 2, N33/3

4. Tylotopalla robustispinosa (Downie 1959) Eisenack et al. 1973
   4. CLY/PS 1, 2, S38/4

5,8. Peteinosphaeridium sp.
   5. OER/PS 8, 1, Y56/1
   8. OER/PS 3, 2, R50/4

6. Striatotheca sp.
   6. HAF/PS 1, 1, R38

7. Acritarch sp.
   7. HAF/PS 1, 1, U34/4

9. Frankea sp.
   9. HAF/PS 1, 4, R38

10. Acritarch sp.
   10. OER/PS 3, 2, S45/2 (x750)

PLATE 33

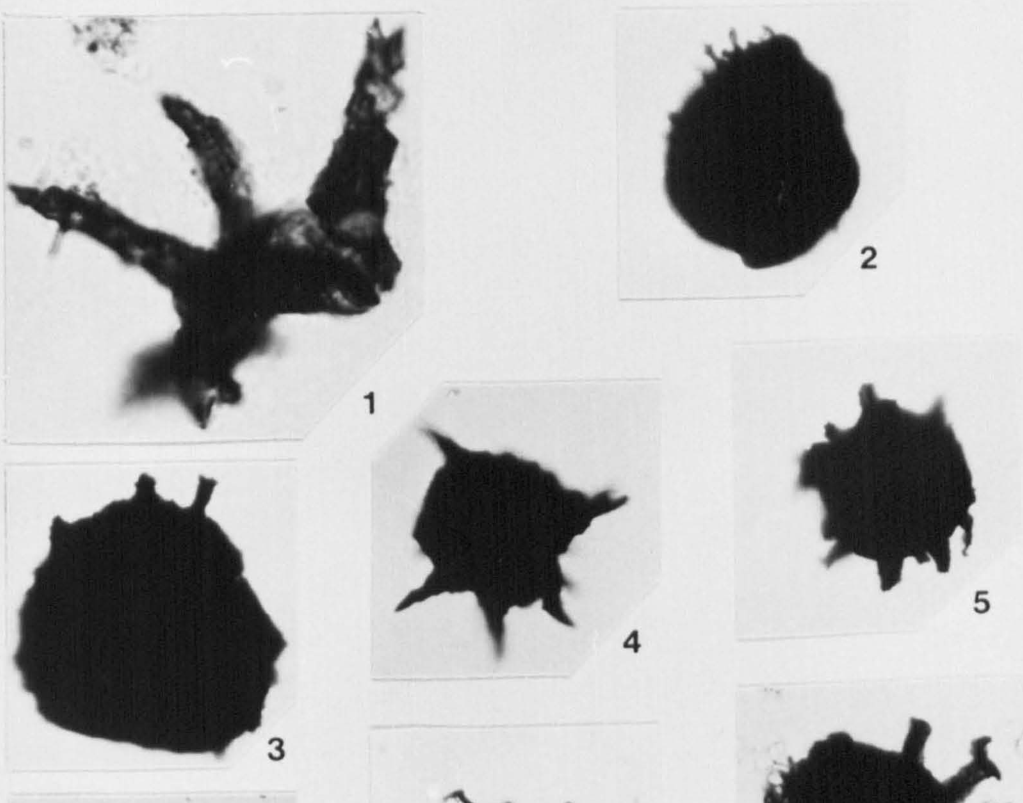


PLATE 34

Magnifications x1000 unless otherwise stated

Figure

1. Ammonidium palmitella (Cramer & Diez 1972a) Dorning 1981a
   1. VC/PS 3

2. Gracilisphaeridium encantador (Cramer 1970) Eisenack et al. 1973
   2. MPA 26084

3. Ammonidium waldronense (Tappan & Loeblich 1971) Dorning 1981a
   3. MPA 26084

4. Multiplicisphaeridium cladum Downie 1963
   4. MPA 26083

5. Dateriocradus algerensis (Cramer & Diez 1972a) Dorning 1981a
   5. MPA 26084

6. Cymbosphaeridium cf. eurnes (Cramer & Diez 1972a) Dorning 1981a
   6. MPA 26083

PLATE 34

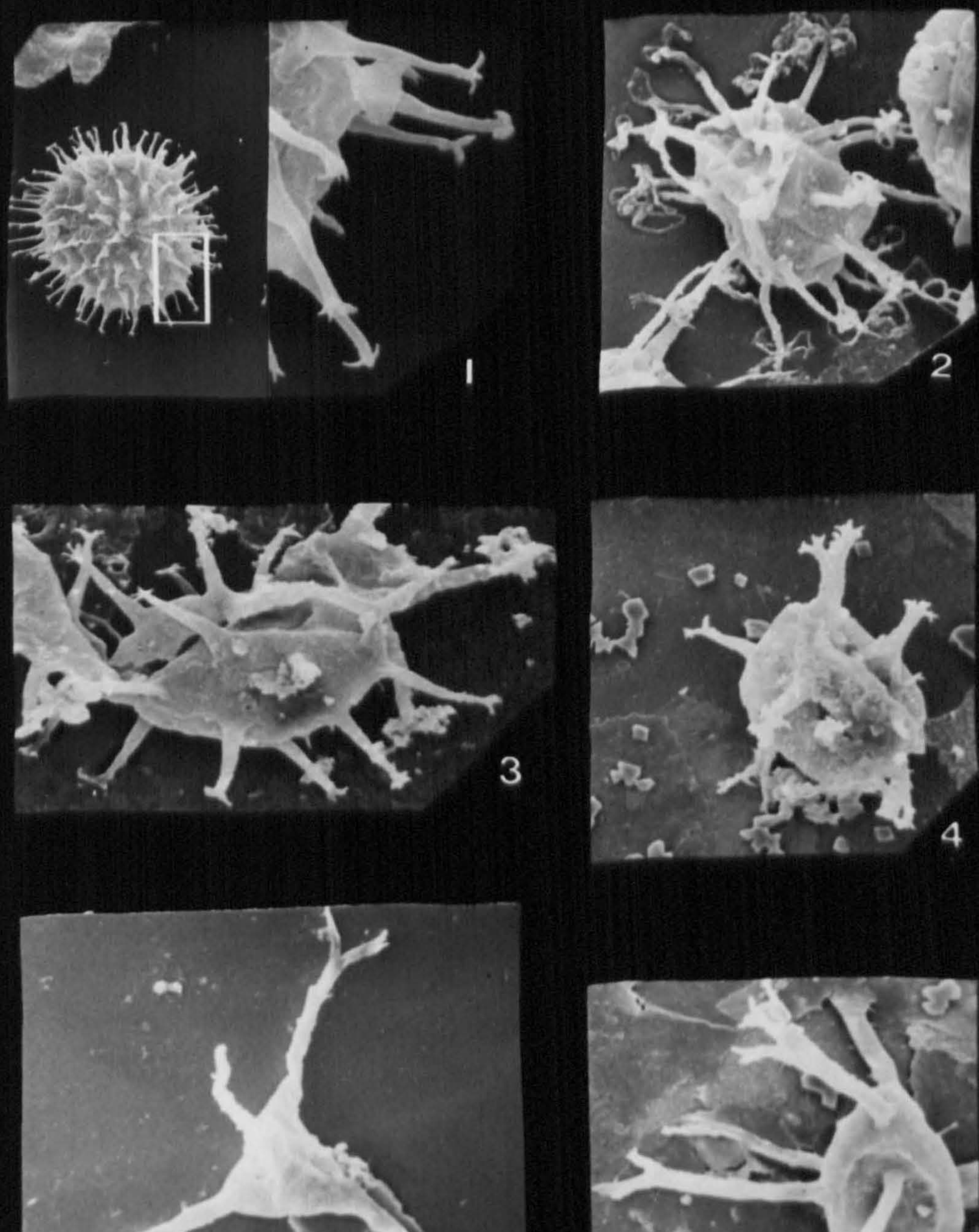


PLATE 35

Magnifications x1000 unless otherwise stated

Figure

1. *Michrystridium stellatum* Deflandre 1945
   1. MPA 26084 (x1500)

2. *Multiplicisphaeridium arbusculum* Dorning 1981a
   2. MPA 26073

3-4. *Salopidium woolhopensis* Dorning 1981a
   3. MPA 26084
   4. MPA 26083

5. *Estiastra barbata* Downie 1963
   5. MPA 26084

6. *Tylotopalla robustispinosa* (Downie 1959) Eisenack *et al*. 1973
   6. MPA 26084

PLATE 35

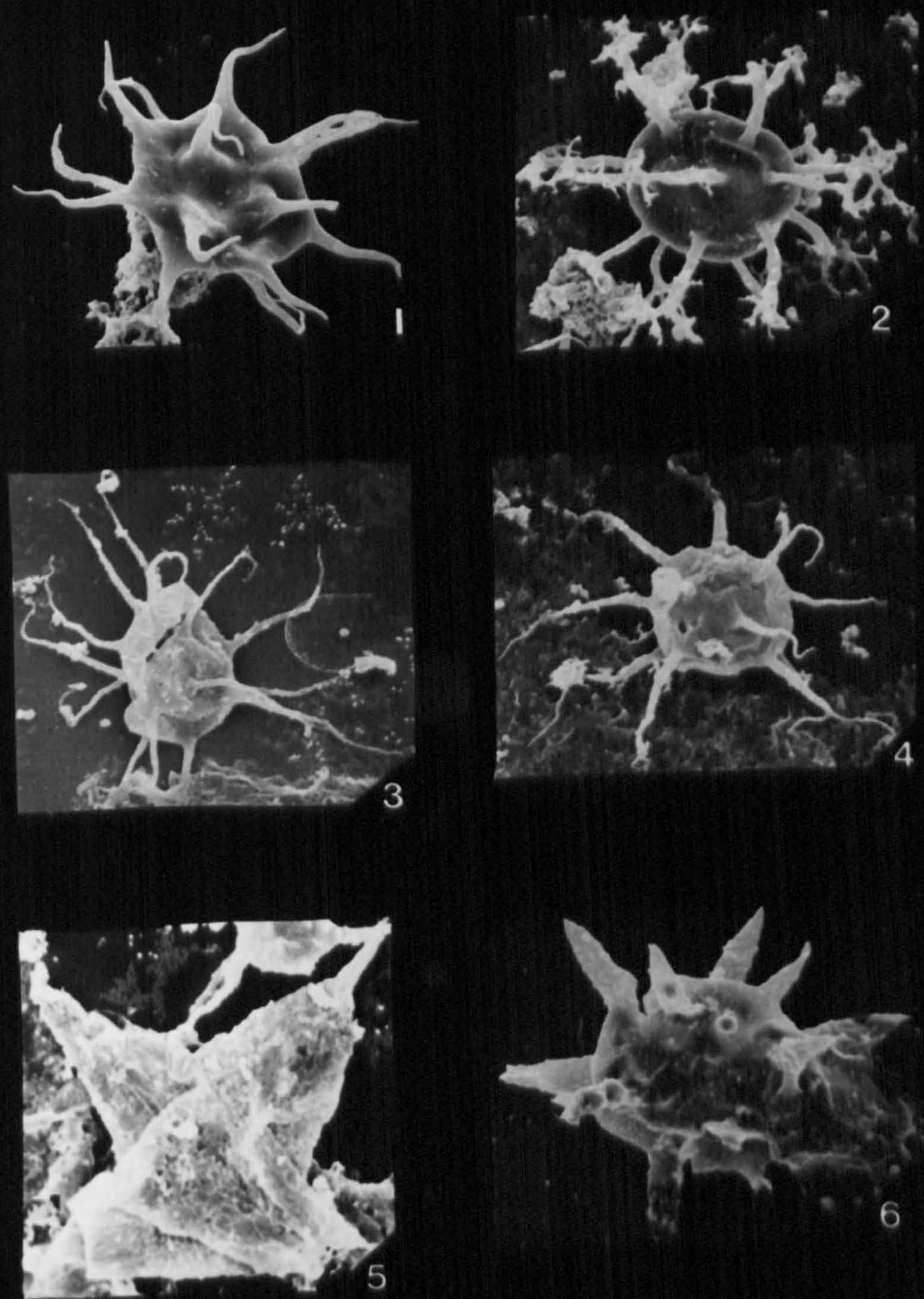


PLATE 36

Magnifications x500 unless otherwise stated

Figure

1,2. Tylotopalla wenlockia Dorning 1981a

1. MPA 26072

2. MPA 26059

3-4. Visbysphaera oligofurcata (Eisenack 1954) Lister 1970

3. MPA 26083

4. MPA 26083

5. Lophosphaeridium citrinum Downie 1963

5. MPA 26084

6. Cymatiosphaera octoplana Downie 1959

6. WC/PS 2

PLATE 36

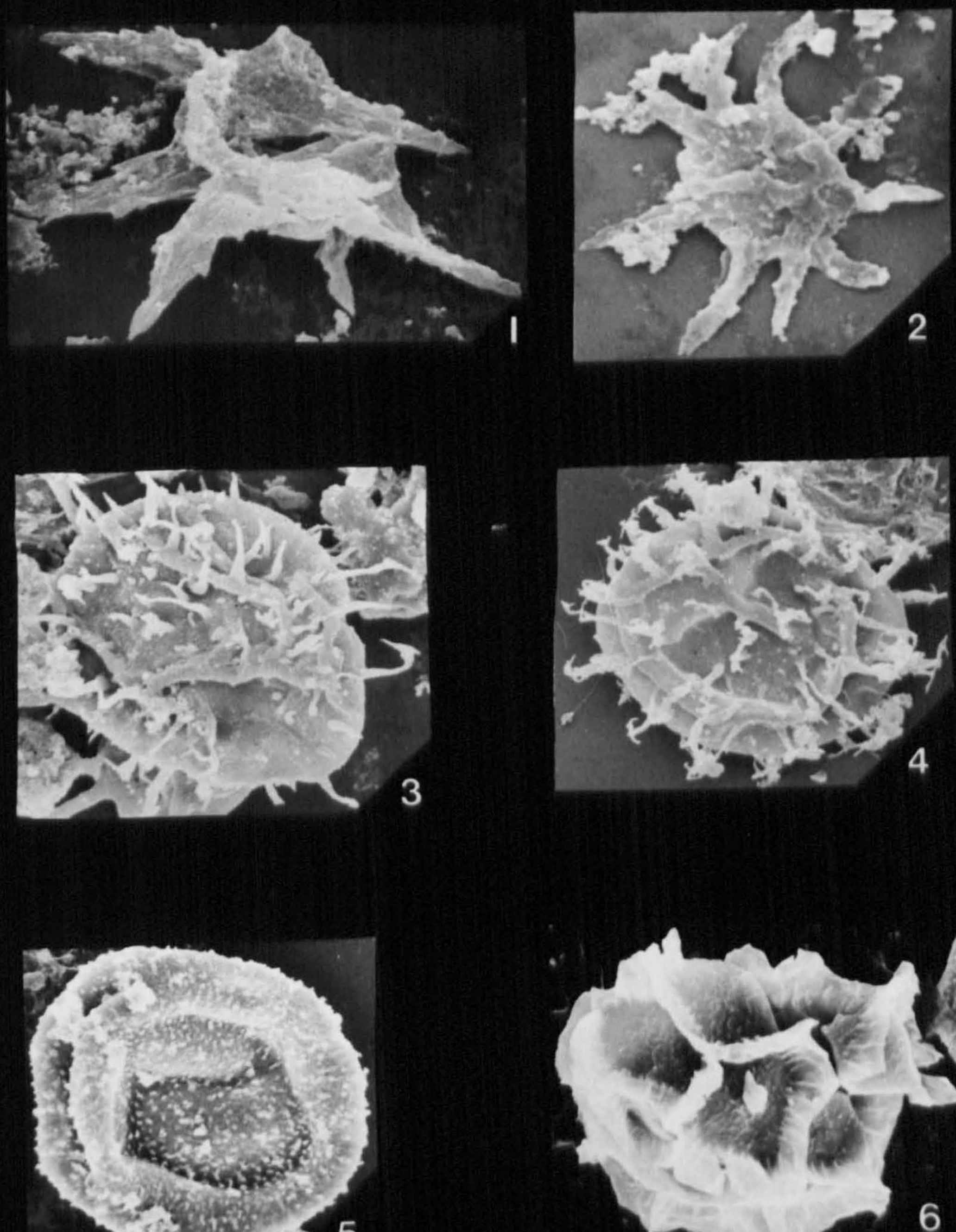


PLATE 37

Acritarchs illustrating different values of the Acritarch Colour Alteration Index (AAI) (after Legall et al. 1981) from studied sections across the early Wenlock shelf.

Magnifications x500 unless otherwise stated

Figure

1, 5-7. Leiosphaeridia wenlockia Downie 1959

1. Tortworth Inlier, BR/PS 1, 2, G42/2 (Alteration Index 3)
5. Lower Hill Farm B, MPA 26084, F1, H22/2 (Alteration Index 2)
6. Lower Hill Farm B, MPA 26073, F1, D32/1 (Alteration Index 2)
7. Whitwell Coppice, WC/PS 8, F1, S22/2 (Alteration Index 2)

2-4, 8-9. Leiosphaeridia laevigata Stockmans & Willière 1963

2. Tortworth Inlier, BR/PS 4, 1, T32/2 (Alteration Index 3)
3. Tortworth Inlier, BR/PS 1, 2, M34/2 (Alteration Index 3)
4. Eastnor Park Bo, MPA 28411, F1, S32/4 (Alteration Index 4)
8. Whitwell Coppice, WC/PS 13, F1, T34/2 (Alteration Index 2)
9. Dolyhir, DOL/PS 2, F1, S32/2 (x750) (Alteration Index 2)

PLATE 37

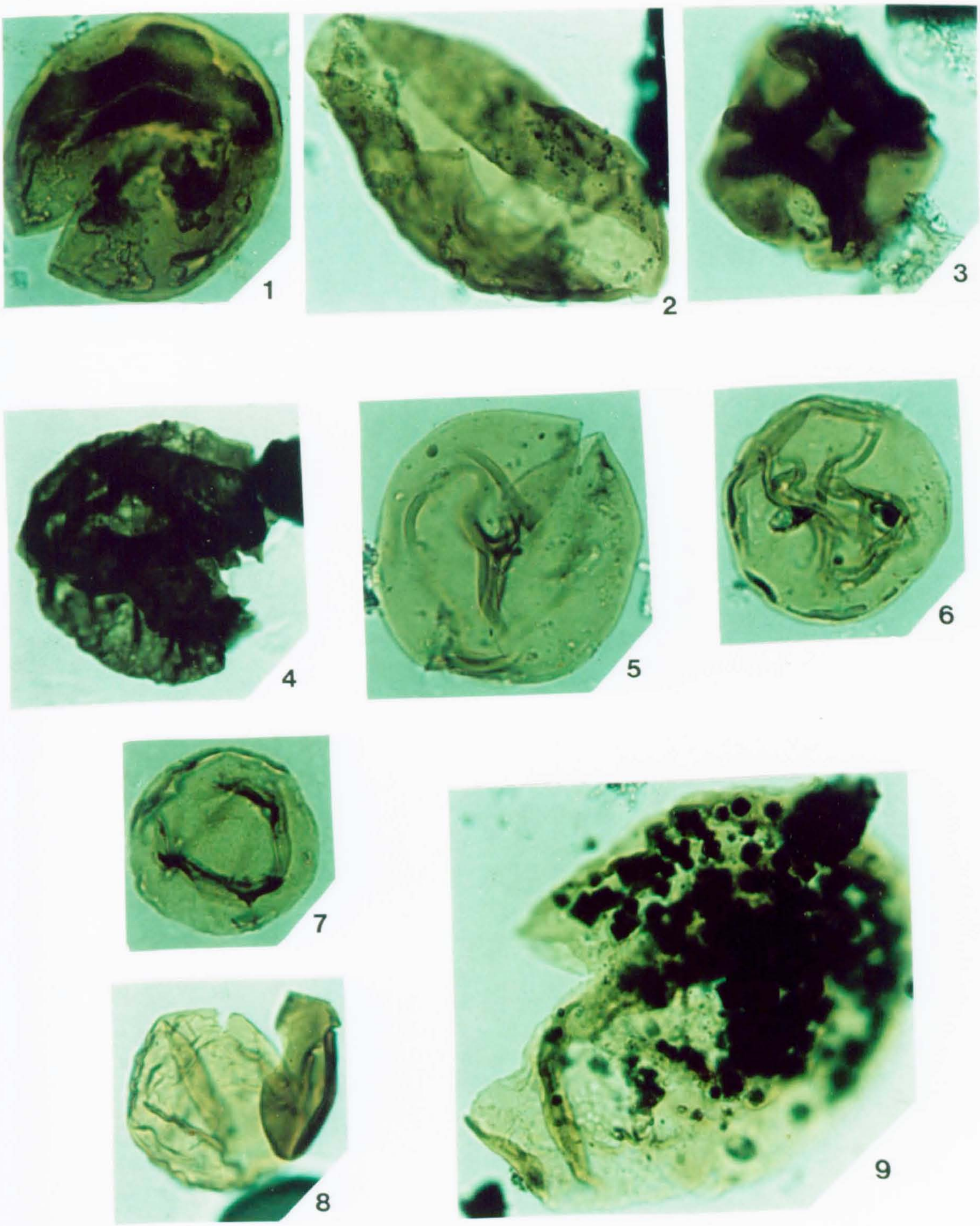


PLATE 38

Acritarchs illustrating different values of the Acritarch Colour Alteration Index (AAI) (after Legall et al. 1981) from studied sections across the early Wenlock Welsh basin.

Magnifications x500 unless otherwise stated

Figure

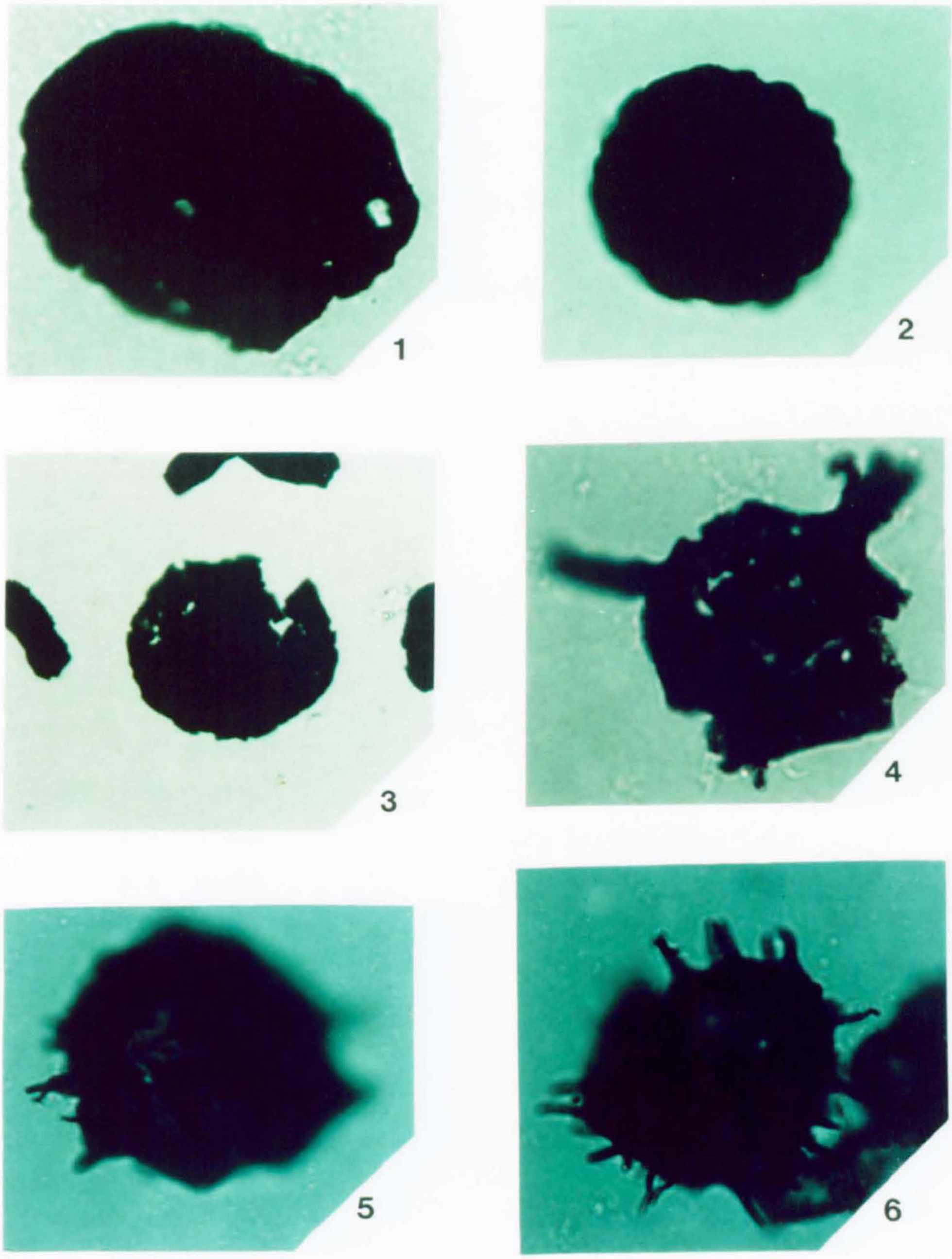
1-3. Leiosphaeridia sp.

1. Llanrwst Section, BRA/PS 3, 1, T34/5 (Alteration Index 5)
2. Conway Section, RHAN/PS 1, 2, S32/2 (Alteration Index 5)
3. Llanrwst Section, CS/PS 2, 2, R32/2 (Alteration Index 5)

4-6. Acanthomorph spp.

4. Llanrwst Section, BRA/PS 2,1, S22/1 (Alteration Index 5)
5. Llanrwst Section, CS/PS 2,2, N33/2 (Alteration Index 5)
6. Conway Section, RHAN/PS 1,1, T34/1 (Alteration Index 5)

PLATE 38



APPENDIX 1

Samples for the Lower Hill Farm and Eastnor Park borehole are registered in the British Geological Survey's MPA series, the MPA numbers and the corresponding depths for the two sections are shown below.

(i) The Lower Hill Farm borehole

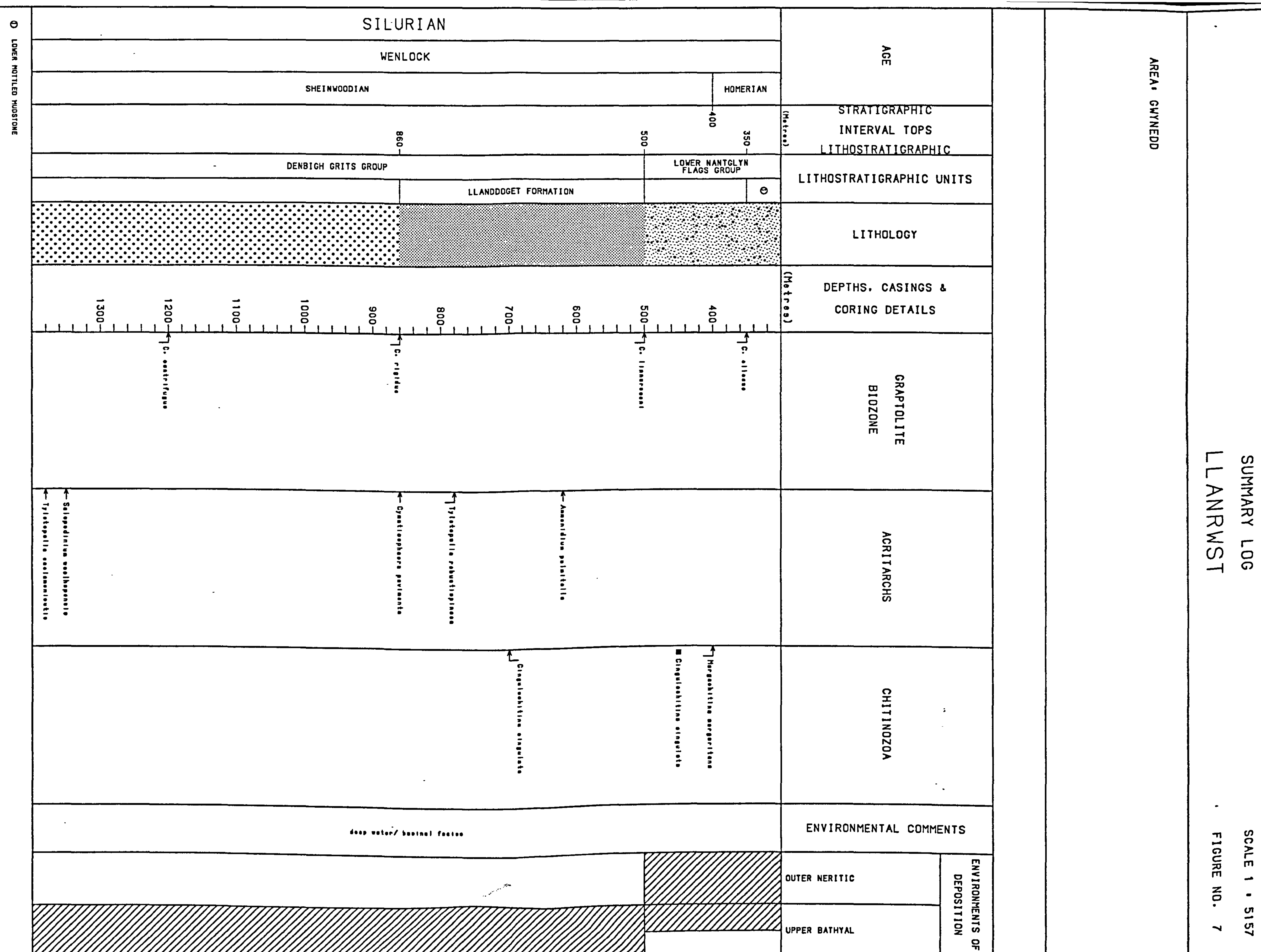
Sample Number	Depth (Metres)
MPA 26045	63.51-64.69
MPA 26046	67.54-68.97
MPA 26047	72.21-73.71
MPA 26048	73.71-75.16
MPA 26049	76.73-78.28
MPA 26050	79.86-81.13
MPA 26051	85.62-87.20
MPA 26052	91.92-93.42
MPA 26053	96.47-97.99
MPA 26054	101.04-102.57
MPA 26055	105.64-107.14
MPA 26056	111.68-113.36
MPA 26057	117.86-119.40
MPA 26058	123.82-125.43
MPA 26059	129.95-131.45
MPA 26060	134.57-136.04
MPA 26061	139.14-140.64
MPA 26062	144.98-146.45
MPA 26063	150.80-152.32
MPA 26064	155.47-156.97
MPA 26065	160.25-161.77
MPA 26066	165.00-166.52
MPA 26067	170.79-172.26
MPA 26068	175.26-176.87
MPA 26069	180.62-182.17
MPA 26070	186.36-187.88

MPA 26071	190.58-192.10
MPA 26072	196.72-198.48
MPA 26073	198.48-199.14
MPA 26074	199.14-200.05
MPA 26075	200.05-201.65
MPA 26076	203.12-204.65
MPA 26077	207.92-209.50
MPA 26078	212.83-214.35
MPA 26079	217.55-219.13
MPA 26080	222.48-223.95
MPA 26081	227.10-228.68
MPA 26082	231.42-232.99
MPA 26083	234.57-236.07
MPA 26084	239.14-239.66

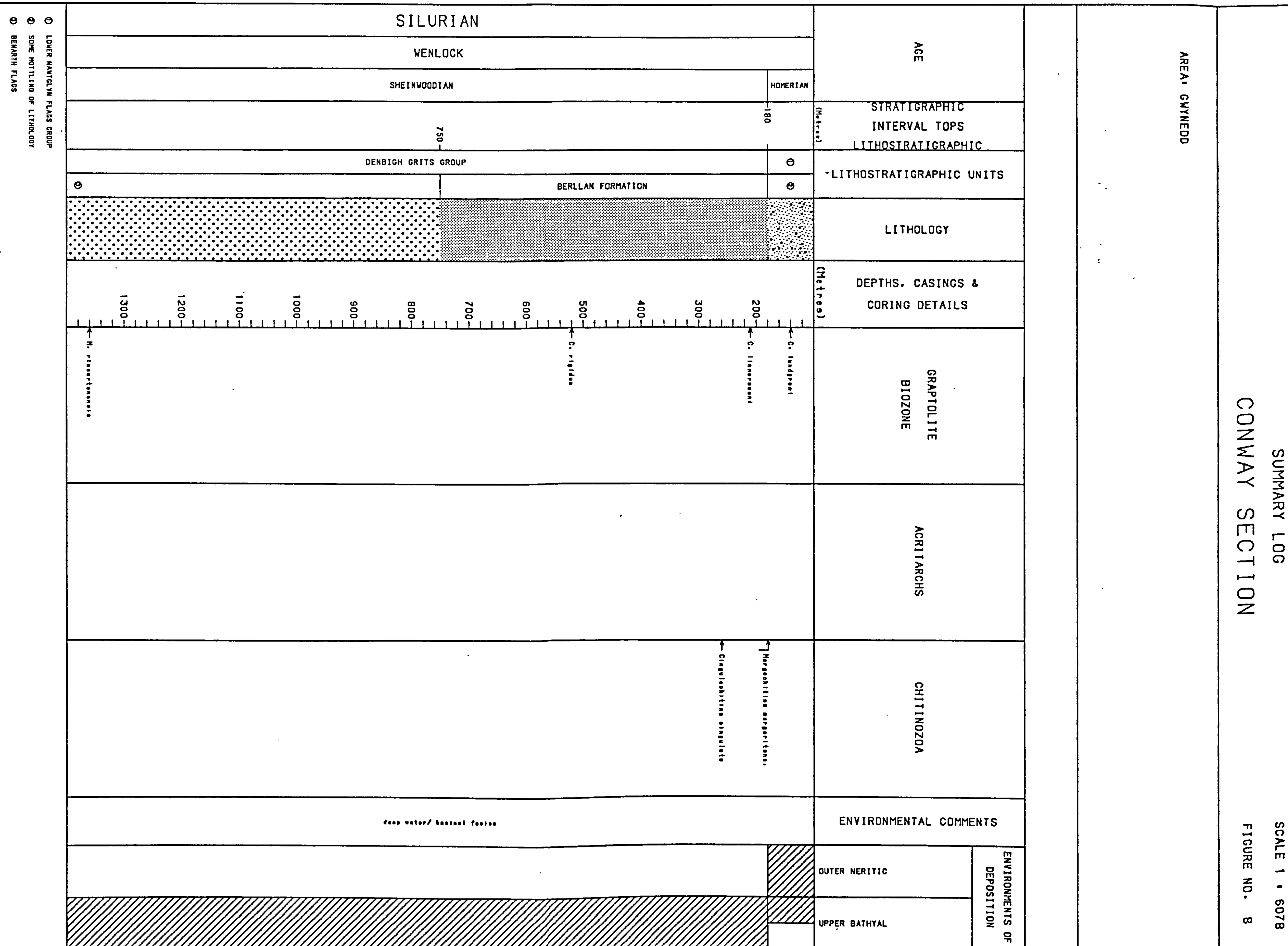
(ii) The Eastnor Park borehole

Sample Number	Depth (Metres)
MPA 28474	5.08
MPA 28475	7.49
MPA 28476	11.70
MPA 28477	16.18
MPA 28478	20.20
MPA 28479	24.00
MPA 28480	29.50
MPA 28481	31.80
MPA 28482	33.60
MPA 28483	35.60
MPA 28484	37.45
MPA 28410	39.60
KD/BS3	40.43-41.93
MPA 28411	42.10
MPA 28412	43.20
MPA 28413	43.70
MPA 28414	43.78
KD/BS2	45.70-46.65

MPA 28485	46.40
MPA 28415	47.80
KD/BS1	48.10-49.59
MPA 28416	50.10



⊖ LOWER MOTTLED MUDSTONE
SILURIAN
WENLOCK
SHEINWOODIAN
HOMERIAN
AGE
STRATIGRAPHIC INTERVAL TOPS LITHOSTRATIGRAPHIC
(Metres)
860
500
400
350
DENBIGH GRITS GROUP
LOWER NANTGLYN FLAGS GROUP
LLANDDOGET FORMATION
⊖
LITHOSTRATIGRAPHIC UNITS
LITHOLOGY
DEPTHS, CASINGS & CORING DETAILS
1300
1200
1100
1000
900
800
700
600
500
400
C. centrifugus
C. rigidus
C. linnarssoni
C. ellesae
GRAPTOLITE BIOZONE
Tylotopalla caelamenicutis
Salopidium woolhopensis
Cymatiosphaera pavimenta
Tylotopalla robustispinosa
Ammonidium palmitella
ACRITARCHS
Cingulochitina cingulata
■ Cingulochitina cingulata
Margachitina margaritana
CHITINOZOA
deep water/ basinal facies
ENVIRONMENTAL COMMENTS
OUTER NERITIC
UPPER BATHYAL
ENVIRONMENTS OF DEPOSITION
AREA: GWYNEDD
SUMMARY LOG
LLANRWST
SCALE 1 : 5157
FIGURE NO. 7


SUMMARY LOG
CONWAY SECTION
SCALE 1 : 6078
FIGURE NO. 8
AREA: GWYNEDD
AGE
SILURIAN
WENLOCK
SHEINWOODIAN
HOMERIAN
STRATIGRAPHIC INTERVAL TOPS
(Metres)
750
180
LITHOSTRATIGRAPHIC
LITHOSTRATIGRAPHIC UNITS
DENBIGH GRITS GROUP
BERLLAN FORMATION
LITHOLOGY
DEPTHS, CASINGS & CORING DETAILS
(Metres)
1300
1200
1100
1000
900
800
700
600
500
400
300
200
GRAPTOLITE BIOZONE
M. riccartonensis
C. rigidus
C. linnarssoni
C. lundgreni
ACRITARCHS
CHITINOZOA
Cingulochitina cingulata
Margachitina margaritana
ENVIRONMENTAL COMMENTS
deep water/ basinal facies
ENVIRONMENTS OF DEPOSITION
OUTER NERITIC
UPPER BATHYAL
① LOWER NANTGLYN FLAGS GROUP
② SOME MOTTLING OF LITHOLOGY
③ BENARTH FLAGS

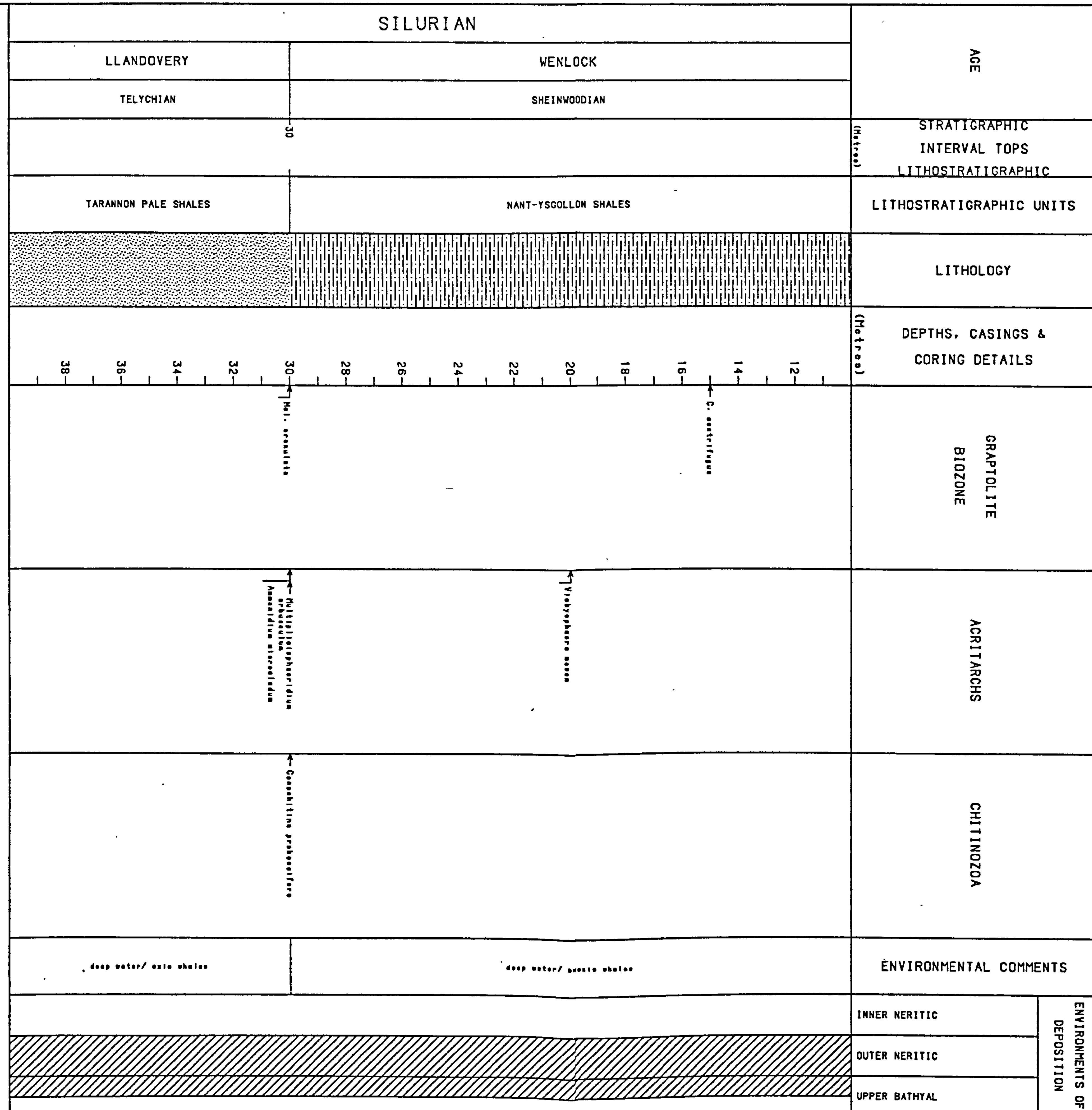
SUMMARY LOG

PISTYLL QUARRY

AREA: POWYS

SCALE 1 : 147

FIGURE NO. 6

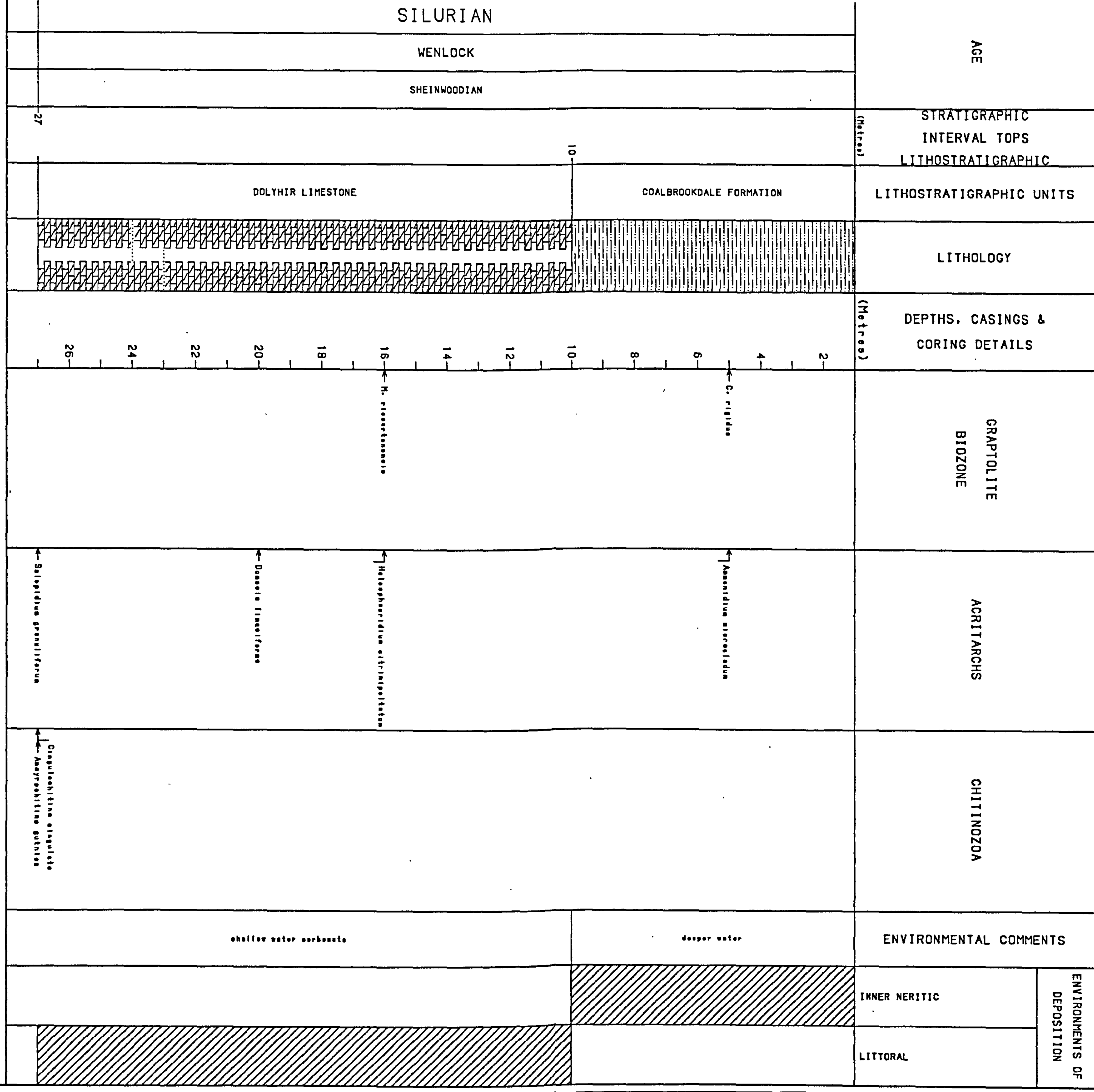


AREA: POWYS

SUMMARY LOG
DOLYHIR

SCALE 1 : 128

FIGURE NO. 5



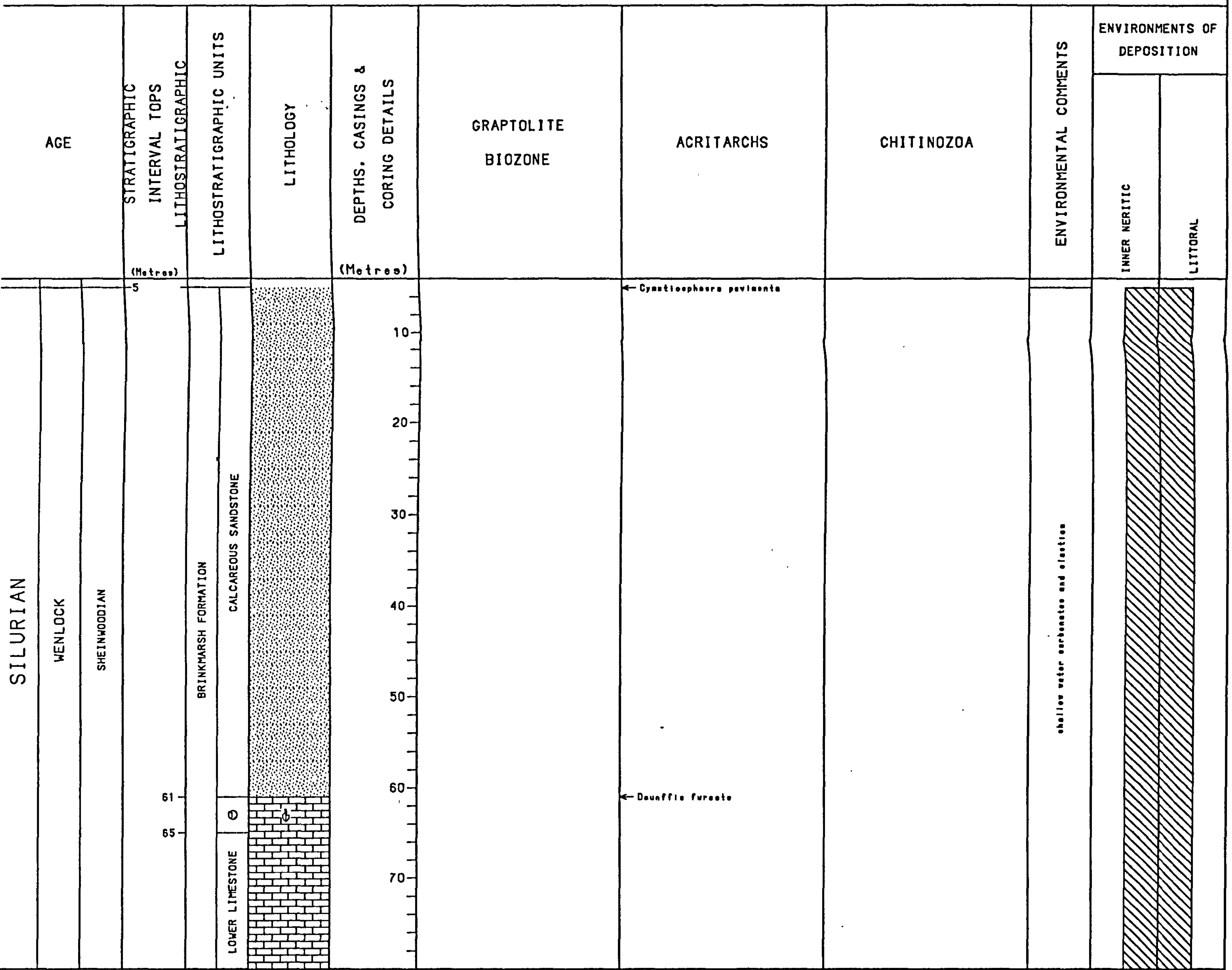
SUMMARY LOG

TORTWORTH INLIER

SCALE 1 : 500

FIGURE NO. 4

AREA: GLOUCESTERSHIRE



PYCNACTIS BAND

SUMMARY LOG

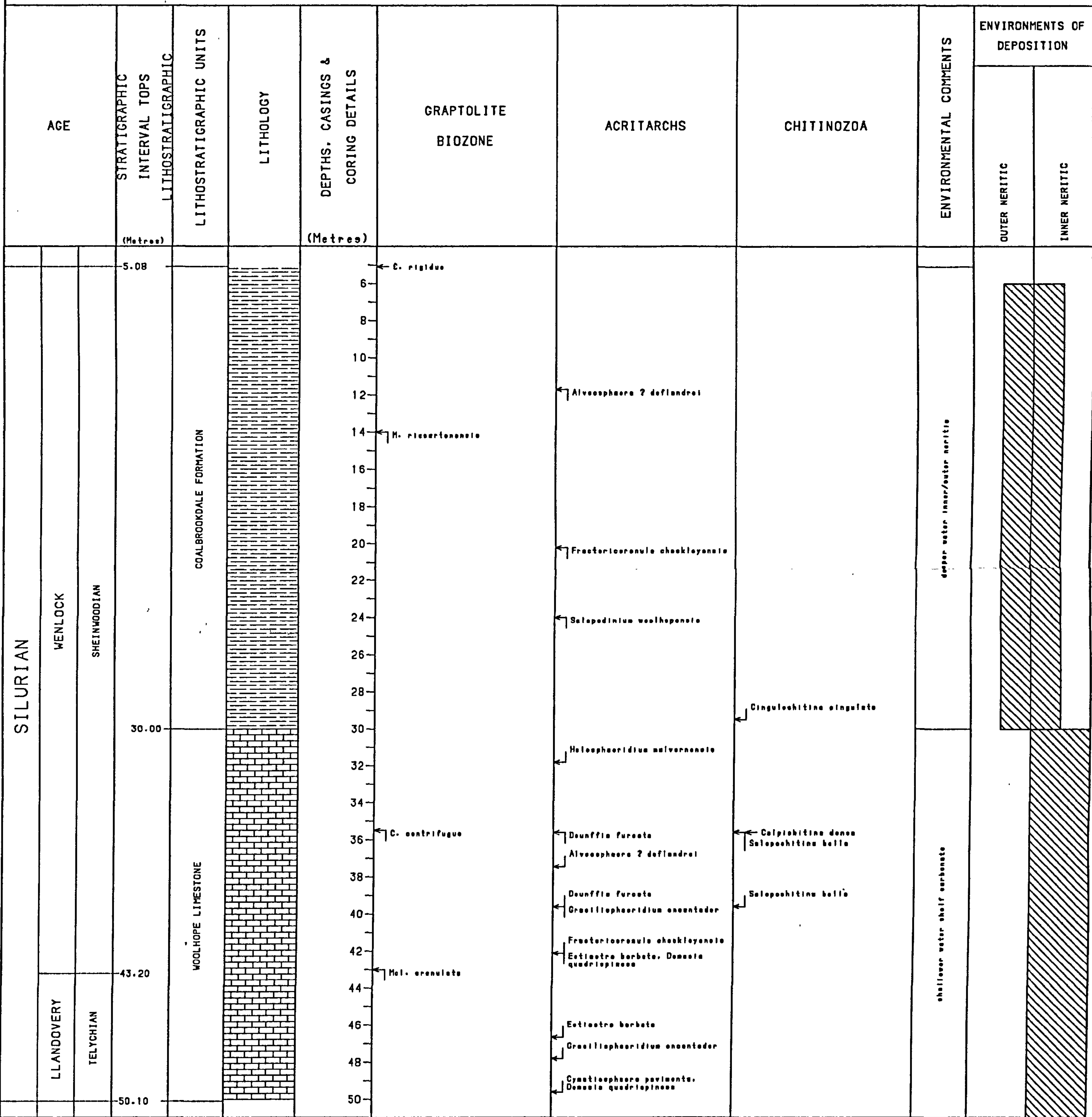
EASTNOR PARK BOREHOLE

SCALE 1 : 216

FIGURE NO. 3

AREA: HEREFORD AND WORCESTER

COMPANY: B.G.S.



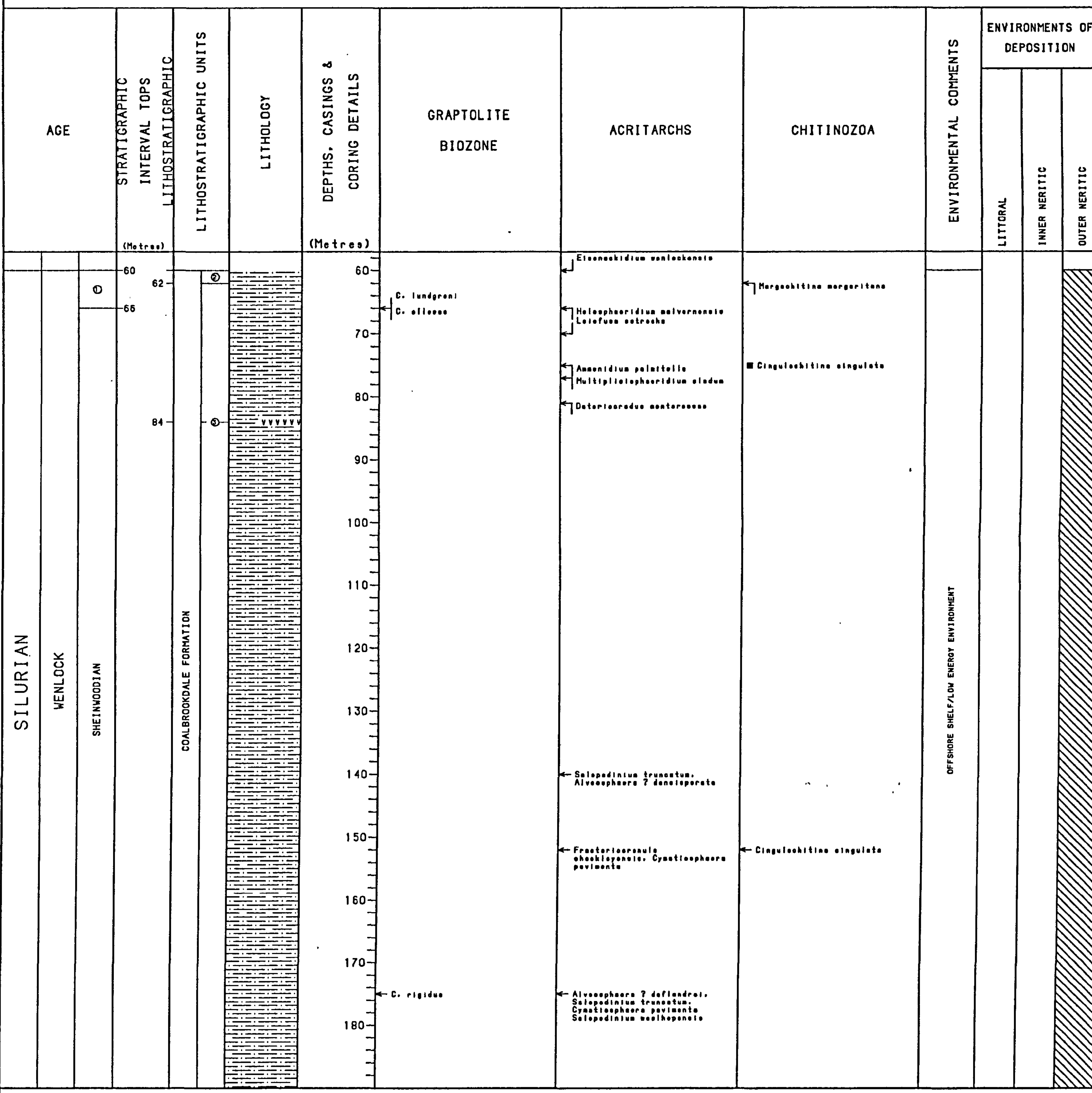
SUMMARY LOG

WHITWELL COPPICE

SCALE 1 : 644

FIGURE NO. 2

AREA: SHROPSHIRE



① HOMERIAN
② NODULAR
③ BENTONITE

SUMMARY LOG

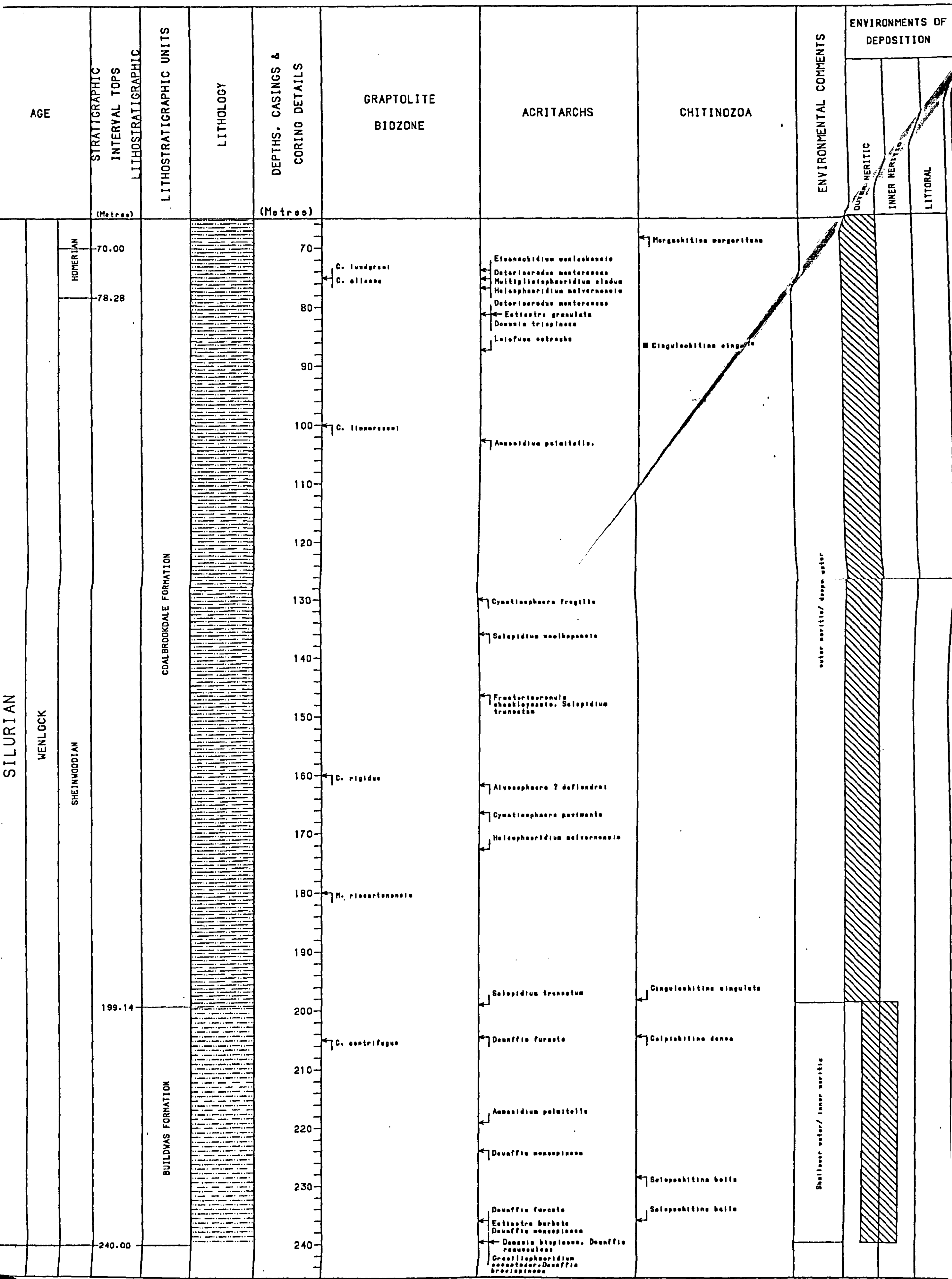
LOWER HILL FARM BOREHOLE

SCALE 1 : 600

FIGURE NO. 1

AREA: SHROPSHIRE

COMPANY: BGS



APPENDIX 3

A REVIEW OF:-

1989 Le Hérissé, A. Acritarchs et Kystes d'algues Prasinophycées du Silurien de Gotland Suéde. Palaeontographica Italica, 76, 57-302 and a comparison with the present study.

INTRODUCTION

Le Hérissé recovered a well preserved and diversified palynoflora of acritarchs (incertae sedis) and cysts of Prasinophycean algae from a cored section and 138 exposures of the Silurian (lower Llandoverian to upper Ludlovian) marine succession on the Swedish island of Gotland. He described 180 taxa, of which 35 species or subspecies are new. He also revised the criteria used for systematic differentiation of the acritarchs and proposes a key for the identification of all genera encountered on Gotland.

CLASSIFICATION

Le Hérissé relates four acritarch genera to the Prasinophycean algae; these being Cymatiosphaera, Leiosphaeridia, Pterospermopsis and the Tasmanitids.

To distinguish the other acritarch genera, he uses a number of Taxonomic criteria; these being:-

1. The form of the vesicle and the symmetry.

2. The type and distribution of the ornament on the surface of the vesicle.

3. The relationship of the ornaments with the vesicle, for instance is there communication with the central activity.

4. The wall structure; is the vesicle single-walled, double-walled but the walls are in contact, or are there two separated walls (a cavate structure).?

From these criteria, Le Hérissé derived three larger categories of acritarch. These are:

1. Acritarchs with axial symmetry and homomorphic poles.

2. Acritarchs with axial symmetry and heteromorphic poles.

3. Acritarchs with regular symmetry.

REMARKS ON THE COMPOSITION OF THE WENLOCK PALYNOFLORA OF GOTLAND

At the top of the Llandovery into the base of the Wenlock within the Visby Formation, Le Hérissé noted an assemblage consisting of Ammonidium microcladum, Salopidium granuliferum, Deunffia furcata, Deunffia monospinosa, Oppilatala cara, Cymatiosphaera heloderma, Domasia quadrispinosa, Gracilisphaeridium encantador and Visbysphaera pirifera minor. He notes the special importance of the genera Deunffia and Domasia, and singles out the first appearance of Deunffia ramusculosa in the Lower Visby Formation as being of correlatable value with the Wenlock type area (see Mabillard and Aldridge, 1985). He also singles out the species Deunffia monospinosa (Dorning and Hill, 1986).

In the upper Visby Formation, Le Hérissé records an assemblage consisting of Deunffia brevispinosa, Estiastra barbata and Multiplicisphaeridium forquillum. This assemblage he compares with assemblages from the extreme base of the Wenlock in Belgium, Great Britain and Podolia.

The base of the Homerian (in the Slite Formation) is marked by the first appearances and assemblage association of Eisenackidium wenlockensis and Leptobrachion arbusculiferum.

The occurrence in the late Wenlock and Ludlow of Neoveryhachium carminae is used to discount a series of Silurian palaeolatitudinal assemblage variations first suggested by Cramer and Diez (see various papers between 1969-1974).

SYSTEMATIC SECTION

Species common to Gotland and my studied sections are listed and discussed below.

Species recorded by Le Hérissé are:-

Division Chlorophyta
Class Prasinophyceae

Cymatiosphaera heloderma. Cramer and Diez; Le Hérissé, pp. 73-74, pl. 1 figs. 1, 5-8, 16, 17.

Remarks

Le Hérissé recorded this species from the Högklint Formation of Gotland that is from part of the lower Wenlock.

Pterospermopsis martinii. Cramer; Le Hérissé, pp. 78-79, pl. 4, figs., 10-14 ?- Pterospermella sp.A.

Remarks

Le Hérissé includes forms with both a foveolate and a reticulate central capsule within Pterospermopsis martini. If this is followed then both Pterospermella foveolata and Pterospermella sp.A could be placed in this species.

Le Hérissé recorded Pterospermopsis martinii from the Upper Visby Formation and from the base of the Högklint Formation (lower Wenlock).

Group Acritarcha Evitt, 1963.

Genus Ammonidium. Lister, 1970, restrict Le Hérissé.

Remarks

In his revised diagnosis Le Hérissé distinguishes the three genera Ammonidium, Hapsiodopalla, Playford 1977 and Naevisphaeridium Wicander, 1974 mainly on vesicle ornamentation differences.

Ammonidium microcladum. (Downie, 1963); Le Hérissé, pp. 82-84, pl. 5, figs. 7-13.

Remarks

Le Hérissé included, Ammonidium waldronense, in his synonymy for this species, accounting for the difference in vesicle ornamentation by suggesting intra-specific variation.

He records this species from the Visby, Högklint, Slite and Hemse Formations (upper Llandovery to lower Ludlow).

?Ammonidium sp. 1. Hill; Le Hérissé, p. 84, pl. 5, fig. 6 ?= Ammonidium granulosum sp. nov.

Remarks

It is possible that these two species are synonymous following Le Hérissé's description.

He records it from the Visby Formation in Gotland (Llandovery - Wenlock boundary).

Carminella maplewoodensis. Cramer; Le Hérissé, pp. 88-89, pl. 5, fig. 16.

Remarks

Le Hérissé recovered this species from the Visby and Slite Formations, (lower to middle Wenlock).

Cymbosphaeridium cf. ravum. (Downie); Le Hérissé, p. 91, pl. 7, fig. 9-13.

Remarks

Le Hérissé 'compares' his specimens to the original diagnosis and illustrations (Downie, 1963, pl. 91, fig. 6) although they are probably synonymous.

He records Cymbosphaeridium cf. ravum from the Högklint Formation (lower Wenlock).

Deunffia brevispinosa. Downie; Le Hérissé, pp. 94-95, pl. 8, figs. 1-2.

Remarks

Le Hérissé notes a variability in the vesicle shape from subcircular to ovoid in this species. The species was recovered from the Visby and Högklint Formations (upper Llandovery to lower Wenlock).

Deunffia furcata. Downie; Le Hérissé, pp. 95-96, pl. 8, fig. 4.

Remarks

This species was recovered from the Visby and Högklint Formations (lower Wenlock).

Deunffia monospinosa. Downie; Le Hérissé, pp. 96-97, pl. 8, fig. 6.

Remarks

Le Hérissé distinguishes a variety of Deunffia monospinosa which he calls robusta on account of its smaller more rigid process. Deunffia monospinosa was recovered from the lower Visby Formation (lower Wenlock).

Deunffia ramusculosa. Downie; Le Hérissé, pp. 98-99, pl. 8, figs. 7-8.

Remarks

This species was recovered from the Visby and Högklint Formations (lower Wenlock).

Domasia bispinosa. Downie; Le Hérissé, pp. 100-101, pl. 8, fig. 15.

Remarks

This species was recovered from the lower Visby Formation (upper Llandovery to lower Wenlock).

Domasia limaciforme. (Stockmans and Willière); Le Hérissé, pp. 101-103, pl. 8, fig. 19.

Remarks

Le Hérissé suggests that morphologically Domasia limaciforme is very close to the complex of species that includes Domasia elongata and Domasia trispinosa. Domasia limaciforme was recovered from the Visby and Högklint Formations (lower Wenlock).

Domasia quadrispinosa. Hill; Le Hérissé, p. 103, pl. 8, figs. 20, 26, 27.

Remarks

Le Hérissé suggests that due to the co-occurrence of D. quadrispinosa and D. trispinosa and the rarity of the former and the abundance of the latter, that D. quadrispinosa is an abnormal 'mutant' of the main D. trispinosa population. He recovered it from the lower Visby and Högklint Formations (uppermost Llandovery and lowest Wenlock).

Domasia trispinosa. Downie; Le Hérissé, pp. 104-105, pl. 8, figs. 21, 22, 24, 25; pl. 9, figs. 6-7.

Remarks

Le Hérissé discusses the morphological variation of D. trispinosa and suggests a classification that includes four different form types (A-D). He recovered D. trispinosa from the Visby, Högklint and Slite Formations (upper Llandovery to mid Wenlock).

Genus Dictyotidium. Eisenack, emend Staplin, 1961 - Alveosphaera. Kirjanov, 1978.

Remarks

Although Le Hérissé states that the 'reticulation' of specimens referred to Alveosphaera is much smaller than that of Dictyotidium, he says that there is not sufficient morphological criteria to have two separate genera and therefore concludes that Alveosphaera is a junior synonym of Dictyotidium.

Dictyotidium dictyotum. (Eisenack); Le Hérissé, pp. 108-109, pl. 3, figs. 12, 18.

Remarks

Le Hérissé recovered this species from the Visby and Högklint Formations. (upper Llandovery - lower Wenlock).

Dictyotidium faviformis. Schultz; Le Hérissé, pp. 109-110, pl. 3, figs. 3, 6-9, 13, 16 - Dictyotidium cavernosulum. Playford, 1977.

Remarks

Le Hérissé suggests that Dictyotidium cavernosulum is a junior synonym of D. faviformis. Le Hérissé records D. faviformis, throughout the Wenlock and Ludlow of Gotland.

Dictyotidium stenodictyum. Eisenack; Le Hérissé, pp. 111-112, pl. 4, fig. 6-9.

Remarks

Le Hérissé records this species from the Visby, Höglklint and Slite Formations (lower Wenlock).

Duvernayspaera aranaides. (Cramer); emend Le Hérissé, pp. 119-120, pl. 6, figs. 11-15.

Remarks

Le Hérissé emends the diagnosis of Duvernaysphaera aranaides to take into account his observations of a double vesicle wall (the outer wall layer covering the radiating spokes eminating from the central body and also covering the inner central body) and a simple split excystment mechanism. He records D. aranaides from the upper Llandovery and throughout the Wenlock and Ludlow.

Eisenackidium wenlockensis. Dorning; Le Hérissé, pp. 121-122, pl. 9, figs. 14-16.

Remarks

Le Hérissé notes that there is a variation in vesicle length and in process number from those outlined by Dorning 1981. He records E. wenlockensis from the mid-Wenlock to the mid-Ludlow.

Elektoriskos aurora. Loeblich; Le Hérissé, p. 122, pl. 10, figs. 3-4 ?= Elektoriskos williereae. (Deflandre and Deflandre - Rigaud, 1965) Vanguestaine, 1979.

Remarks

Le Hérissé suggests synonymy between Elektoriskos aurora and Elektoriskos williereae, although he does not discuss branching of the processes in his description of E. aurora. He records Elektoriskos aurora from the Visby Formation (lower Wenlock).

Estiastra barbata. Downie; Le Hérissé, p. 124, pl. 10, figs. 7-10.

Remarks

Le Hérissé retains this species within the genus Estriastra and he compares it with other species of Estiastra, such as E. avita Loeblich and Tappan, 1978, E. magna Eisenack, 1959 and E. rhytidoa Wicander and Wood, 1981. Le Hérissé records the species from the upper Visby Formation (lower Wenlock).

Genus Evittia. (Brito, 1967) emend. Lister, 1970 - Diexallophasis. Loeblich, 1970.

Remarks

Le Hérissé suggests that Diexallophasis Loeblich, 1970 is a junior synonym of Evittia (Brito, 1967). He also includes the genus Exochoderma Wicander, 1974 in his synonymy. If a distinction is made between forms possessing a lenticular vesicle (see Evittia Loeblich, 1979, p. 721) and those with a spherical vesicle (see Diexallophasis Loeblich, 1970, p. 714), then both genera may be retained. Although if Lister's emended diagnosis (1970, p. 66) is followed, then both genera are synonymous and Evittia is senior.

Evittia denticulata denticulata, (Cramer). nov. comb. Le Hérissé, pp. 126-127, pl. 11, figs. 1-6 - Diexallophasis denticulata (Stockmans and Williére, 1963).

Remarks

Le Hérissé records this species from the upper Llandovery through to the Ludlow. Le Hérissé also distinguishes another four subspecies of Evittia denticulata including Evittia denticulata gotlandica (Cramer).

Evittia robustispinosa. (Downie) Lister; Le Hérissé, pp. 129-130, pl. 12, figs. 6-10 - Tylotopalla robustispinosa. (Downie) Eisenack *et al.*, 1973 - Tylotopalla wenlockia. Dorning, 1981a.

Remarks

Le Hérissé attributes this species to Evittia rather than Tylotopalla because he suggests that species of Tylotopalla should have longitudinal crests along the processes. He also proposes synonymy with Tylotopalla wenlockia Dorning 1981a suggesting that this is just an intraspecific variant. Le Hérissé records E. robustispinosa from the Visby, Slite and basal Mulde Formations (lower to upper Wenlock).

Eupoikilofusa striatifera typica, Cramer and Diez.

Remarks

Le Hérissé follows Cramer and Diez (1972) and separates subspecies stericula from subspecies typica on the fact that the former has longer processes. He records Eupoikilofusa striatifera typica from the upper Llandovery through to the upper Ludlow.

Florisphaeridium wenlockensis, Dorning, 1981a.

Remarks

Le Hérissé states that observed specimens conform to the original diagnosis, apart from a granulation on the surface of the vesicle. Le Hérissé recovers this species from part of the upper Visby Formation and from the Slite Formation (lower Wenlock).

Gorgonisphaeridium succinum, Lister; Le Hérissé, p. 140, pl. 14, figs. 10-13.

Remarks

Le Hérissé notes that there are two different morphotypes of this species. The variation is both in the number and length of the processes. He records it from the mid-Wenlock through to the upper Ludlow.

Gracilisphaeridium encantador, (Cramer); Le Hérissé, pp. 141-142, pl. 14, figs. 1,2.

Remarks

Le Hérissé notes two morphotypes, one with shorter processes equals (¼ diameter of vesicle) and one with longer processes equals (1/3 to ½ diameter of vesicle). He also suggests that excystment is by a simple split and that previously recorded cyclopyles are just a preservational aberration. He records this species from the Visby Formation (lower Wenlock).

Helosphaeridium critinipeltatum, (Cramer and Diez); Le Hérissé, pp. 143-144, pl. 17, fig. 1.

Remarks

This species was recovered from the Visby Formation (lower Wenlock).

Helosphaeridium pseudodictyum, Lister; Le Hérissé, p. 144, pl. 17, fig. 2.

Remarks

This species was recovered from the Visby and Slite Formations (lower to mid Wenlock).

Leiofusa estrecha. Cramer; Le Hérissé, pp. 149-150, pl.16, figs. 11-13, 17.

Remarks

Le Hérissé distinguishes a new variety (subspecies) Leiofusa estrecha lacertica which differs from L. estrecha *sensu stricto* because it possesses a micro-ornamentation of granules and nodes that have some longitudinal alignment.

He records Leiofusa estrecha from the Visby and Slite Formations and L. estrecha lacertica from the Visby Formation (upper Llandovery to lower Wenlock).

Leiofusa parvitatis. Loeblich; Le Hérissé, pp. 151-152, pl. 16, fig. 1.

Remarks

Le Hérissé states that excystment was by means of a C-shaped split for this species. He records it from the upper Llandovery to the upper Ludlow.

Leiofusa tumida. Downie; Le Hérissé, p. 152, pl. 16, figs. 14-16.

Remarks

Le Hérissé observes a wrinkled vesicle surface and the beginning of a trochospiral suture on some of his specimens. He records Leiofusa tumida from the Visby and Slite Formations, (lower to middle Wenlock).

Leptobrachion arbusculiferum. (Downie); Le Hérissé, pp. 155-156, pl. 17 = Leptobrachion longhopense Dorning, 1981.

Remarks

Le Hérissé states that Leptobrachion longhopense Dorning 1981 is a junior synonym of Leptobrachion arbusculiferum. Variation in length of the processes and the nature of the process terminations in observed specimens is explained away as intra-specific variation. He records this species from the middle Wenlock through to the middle Ludlow.

Genus Multiplicisphaeridium, Staplin, 1961 restrained Staplin, Jansonius and Pocock, 1965 emend Lister, 1970 = Dateriocradus Tappan and Loeblich, 1971.

Remarks

Le Hérissé states that Dateriocradus is a junior synonym of Multiplicisphaeridium, stating that the different shape of the vesicle is not sufficient in this case for a split at the generic level.

Multiplicisphaeridium cladum. (Downie); Le Hérissé, pp. 159-160, pl. 18, figs. 13, 18.

Remarks

Le Hérissé recovered this species from the Visby and Slite Formations (late Llandovery to lower Wenlock).

Nanocyclopia sp. Le Hérissé, p. 166, pl. 25, fig. 21 ?= Nanocyclopia sp.

Remarks

The morphology of Nanocyclopia Le Hérissé is very similar to Nanocyclopia sp., although the former is about twice as large. Le Hérissé records it from the lower Wenlock to the upper Ludlow.

Onondagaella asymmetrica, (Deunff); Le Hérissé, pp. 168-169, pl. 20, figs. 3-4.

Remarks

Le Hérissé notes that the observed excystment mechanism was by an epibystra as suggested by Playford, 1977. He records it from the lower Wenlock to the late Ludlow.

Oppilatala fermosa, (Cramer) Le Hérissé; p. 171, pl. 23, figs. 10-13, text fig. 14.8 ?- Oppilatala insolita compacta, Le Hérissé, pp. 175-176, 19-22, figs. 9-12, text, fig. 14.3 ?- Oppilatala smelrorii sp. nov.

Remarks

Although specimens referred to this species appear to have basal plugs to their processes. Le Hérissé states that their is a central connecting canal between process and vesicle. Illustrated specimens appear very similar to Oppilatala smelrorii sp. nov., Process number, dimensions and morphology are all similar.

It is possible that the species Oppilatala insolita compacta Le Hérissé is also a synonym and may just be an intraspecific variant possessing more processes.

Le Hérissé records this species from the Visby Formation (upper Llandovery to Wenlock).

Oppilatala frondis. (Cramer and Diez); Le Hérissé, pp. 171-172, pl. 22, figs. 5, 6, text-fig. 14.10

Remarks

Le Hérissé recovered this species from the upper Llandovery through to the middle Ludlow.

Oppilatala insolita. (Cramer and Diez; Le Hérissé, pp. 172-175, pl. 22, figs. 7, 8, text-fig. 14.2.

Remarks

Le Hérissé, in attempting to sort out the problems with this species, places into synonymy a number of other species including Oppilatala eoplanktonica (*sensu* Downie, 1959) and Dateriocradus monterrosae (*sensu*, Cramer 1970). Although he retains Oppilatala eoplanktonica, (*sensu stricto*, Eisenack, 1955) for forms with 'ramifications' at the ends of their processes.

Le Hérissé records Oppilatala insolita from the Visby, Slite and Halla Foramtions (lower to middle Wenlock).

Oppilatala monterrosae. (Cramer); Le Hérissé, pp. 176-177, pl. 23, figs. 14, 15, text-fig. 14.4 = Dateriocradus monterrosae (Cramer, 1969).

Remarks

As Le Hérissé does not recognise the triangular vesicle shape as a distinguishing 'generic' morphological feature, process morphology (including the fact that with observed specimens processes have plugs at their bases) is used in attributing this species to be Oppilatala. Le Hérissé recorded this species from the upper Visby Formation (lower Wenlock).

Oppilatala ramusculosa ramusculosa. (Cramer and Diez); Le Hérissé, pp. 177-178, pl. 23, figs. 5-7, text-fig. 14-5? = Oppilatala ramusculosa (Deflandre).

Remarks

Le Hérissé states that it is a fault to emphasize the differences between Oppilatala ramusculosa (Cramer and Diez) and Oppilatala ramusculosa (Deflandre); the problem being with the latter, that depending on an authors initiative, specimens may be placed in Multiplicisphaeridium ramusculosum (Deflandre) Lister, 1970 or Oppilatala ramusculosa (Deflandre) Dorning, 1981. Taking all possible morphological variations into account, the species has a recorded range from late Ordovician to upper Devonian.

In his attempt to narrow the morphological confines of one particular species, he records the range of O. ramusculosa ramusculosa as upper Llandovery to lower Wenlock.

Genus Psenotopus. Tappan and Loeblich, 1971

Remarks

Le Hérissé sees the irregular ornament on Psenotopus as being an indication of some symbiotic or parasitic relationship between bacteria or fungi and the acritarch. He has also observed this 'association' before with the genera Schismatosphaeridium and Pulvinosphaeridium. He describes an area on the vesicle of Psenotopus which may have been an attachment point, indicating that the form is colonial and probably benthic.

Psenotopus chondrocheus. Tappan and Loeblich; Le Hérissé, p. 184, pl. 21, figs. 1-4.

Remarks

This species was recorded from the Visby and Slite Formations (lower to middle Wenlock).

Pulvinosphaeridium pulvinellum. Eisenack; Le Hérissé, pp. 185-186, pl. 21, figs. 5-11.

Remarks

Le Hérissé remarks on observed ornamentation on the vesicle of this species consisting of microgranulation and small baculae on the processes. The microgranulation may be orientated into fine radiating striations at the base of the processes. Pulvinosphaeridium pulvinellum was recorded from the Visby, Högklint, Slite and Mulde Formations (lower to upper Wenlock).

Genus Salopidium. Dorning, 1981

Remarks

Le Hérissé states that the term foveolate used by Dorning, 1981 in the original diagnosis for Salopidium is inexact and that the ornamentation on the vesicle is better described as irregular, scabrate or rugose.

Salopidium granuliferum. (Downie); Le Hérissé, pp. 188-189, pl. 24, figs. 11-13.

Remarks

Le Hérissé notes that with SEM study the ornamentation on the vesicle of this species is very dense and can be described as scabrate to rugulate. He recovers this species from the Visby, Slite and Mulde Formations (lower to upper Wenlock).

Salopidium woolhopensis. Dorning; Le Hérissé, pp. 189-190, pl. 24, fig. 15

Remarks

Le Hérissé notes that Salopidium woolhopensis bears a resemblance to Salopidium wenlockensis but the former has longer and fewer processes. Le Hérissé records S. woolhopensis from the upper Visby Formation (lower Wenlock).

Genus Schismatosphaeridium. Staplin, Jansonius and Pocock, 1965

Remarks

Le Hérissé comments on the possible excystment device of Schismatosphaeridium. In particular, he suggests that the circular opening was used as a pressure release valve during excystement. He notes the presence of an operculum on some specimens and suggests that the term pseudopylome is more suitable than the term pore suggested by Dorning, 1981. He also suggests excystment was by means of a simple split.

Schismatosphaeridium guttulaferum. Le Hérissé, p. 191, pl. 25, figs. 5, 6 - Schismatosphaeridium papillatum sp. nov.

Remarks

Schismatosphaeridium papillatum sp. nov. is seen as a synonym of Schismatosphaeridium gutttulaferum. Le Hérissé records it from the Visby, Högklint, Slite and Mulde Formations (upper Llandovery to mid Wenlock).

Schismatosphaeridium cf. rugulosum. Dorning; Le Hérissé, p. 192, pl. 25, fig. 13.

Remarks

This species differs from Schismatosphaeridium rugulosum *sensu stricto* only in the size of the ornamentation.

Le Hérissé recovered Schismatosphaeridium cf. rugulosum from the Visby, Högklint and Hemse Formations (lower Wenlock the lower Ludlow).

Tunisphaeridium parvum. Duenff and Evitt; Le Hérissé, p. 193, pl. 26, fig. 17.

Remarks

Le Hérissé records this species from the lower Visby Formation (upper Llandovery to lower Wenlock).

Tunisphaeridium tentaculiferum, (Martin); Le Hérissé, pp. 193-194, pl. 26, fig. 13.

Remarks

Le Hérissé records this species from the lower Visby Formation and the Slite Formation (upper Llandovery to middle Wenlock).

Genus Tylotopalla. Loeblich, 1970.

Remarks

Le Hérissé retains the genus Tylotopalla for species with short processes and with bifurcated and pointed distal tips. He also follows Loeblich, 1970 in stating that there should be longitudinal ribs running down the process length.

Tylotopalla caelamenicutus, Loeblich; Le Hérissé, pp. 195-196, pl. 26, figs. 5-10.

Remarks

This species was recorded from the upper Visby and Slite Formations (upper Llandovery to middle Wenlock).

Veryhachium checkleyensis, Dorning; Le Hérissé, pp. 197-198, pl. 30, figs. 6-7 = Fractoricoronula checkleyensis.

Remarks

Although Le Hérissé claims that there is free communication between process and vesicle in this species, the illustrations are SEM photographs and therefore it is impossible to see. Le Hérissé also notes a granular micro-ornamentation, but suggests that this is homogenous.

He records this species from the Visby and Högklint Formations (lower Wenlock).

Genus Visbysphaera. Lister, 1970; emend Le Hérissé. pp. 198-201.

Remarks

Le Hérissé emends and expands the original diagnosis of Lister (1970, p. 98) to take account of species with filamentous and anostomosing processes. He also notes that the excystment mechanism, which he observed in several species was by a simple split in the outer periphragm and a corresponding pseudopylome (sometimes complete with operculum) on the endophragm.

Le Hérissé also notes a vesicle microgranulation on many of the species. This is not equally distributed, tending to be concentrated at the base of the processes.

Visbysphaera gotlandica. (Eisenack); Le Hérissé, pp. 207-208, pl. 28, figs. 608, text-fig, 18.6.

Remarks

Le Hérissé comments on two morphotypes of this species, one with irregularly distributed processes, the other type has processes arranged into roughly polygonal areas.

He records this species from the Visby, Högklint and Slite Formations (lower to middle Wenlock).

Visbysphaera meson. (Eisenack); Le Hérissé, pp. 208-210, pl. 28, fig, 9-10, text, fig. 19.7.

Remarks

Le Hérissé records this species from the Visby and Högklint Formations (upper Llandovery to lower Wenlock).

Visbysphaera microspinosa. (Eisenack) group; Le Hérissé, pp. 210-211, pl. 29, figs. 9-14 = Lophosphaeridium microspinosum. (Eisenack, 1954).

Remarks

Le Hérissé states that under the light microscope it is easy to confuse this species with those of Lophosphaeridium. He also did not observe the characteristic excystment mechanism that he observed in other species of Visbysphaera and although he states that this species is double-walled, there are no light microscopic photographs to prove this.

He attributes this species to Visbsysphaera mainly on the heteromorphic process type.

Le Hérissé records this species from the Visby, Högklint, Slite and Mudle Formations (upper Llandovery to upper Wenlock).

Visbysphaera oligofurcata. (Eisenack); Le Hérissé, p. 211, pl. 28, fig. 5, text fig. 19.8.

Remarks

Le Hérissé recovered this species from the Visby and Högklint Formations (uppermost Llandovery - lowest Wenlock).

Visbysphaera pirifera. (Eisenack); Le Hérissé, pp. 212-213, pl. 29, figs. 1-6, text. fig. 19.9 = Visbysphaera dilatispinosa (Downie).

Remarks

Le Hérissé considers Visbysphaera dilatispinosa to be a junior synonym of Visbysphaera pirifera, as he states it is not possible to consistantly differentiate the two species.

He records this species from the Visby and Högklint Formations (uppermost Llandovery to lowest Wenlock).

Visbysphaera cf. pirifera hispanica. (Cramer); Le Hérissé, pp. 214-215, pl. 29, fig. 8, text. fig. 19.11? = Visbysphaera cf. dudleyspinosa. Dorning and Hill, '1991'.

Remarks

Although the overall dimensions of this species are slightly larger, it does bear a resemblance to Visbysphaera cf. dudleyspinosa in morphology. Le Hérissé recovered this species fromd the uppermost Llandovery.

Visbysphera sp.A. Le Hérissé, pp. 214-215, pl. 29, fig. 7? - Visbysphaera varispinosa. Dorning and Hill, '1991' in press.

Remarks

Although Le Hérissé only illustrates one specimen, his description indicates a close morphological proximity to Visbysphaera varispinosa. Dorning and Hill, '1991' in press.

COMMENTS ON:-

1991, Morezydlowska, M. Acritarch biostratigraphy of the lower Cambrian and the Precambrian - Cambrian boundary in southwestern Poland. Fossils and strata, 29.

In an argument that takes into account morphological differences of species that have been attributed to the genus Micrhystridium, Deflandre, 1937 from strata as old as Cambrian to as young as Cretaceous, Morezydlowska establishes two new genera. Asteridium includes species possessing solid processes separated from the interior of the vesicle, while species that have hollow processes communicating with the central body cavity are referred to Heliosphaeridium. She goes on to state that the two new genera differ from Micrhystridium by having a single-layered vesicle wall and by lacking surface sculpture and excystment.

Moczydlowska also proposes a new genus for some specimens previously attributed to Baltisphaeridium (see Baltisphaeridium cerinum, Volkova, 1968), which have solid processes; the genus being Globosphaeridium. Baltisphaeridium, Eisenack, 1958, emend. Eisenack, 1969 is retained for species which posess processes with an inner cavity.

ADDITIONAL REFERENCES

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